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GENERAL VIEW OF THE FAMOUS PORTLAND QUARRIES OF ENGLAND, FROM WHICH PORTLAND CEMENT DERIVED ITS NAME.

These quarries, of which there are over fifty, are situated in Dorsetshire, on the Isle of Portland, a peninsula jutstone, the best quality being found in the top bed and in the northeastern part of the island, the poorest in the southwestern part. It has long been a favorite building stone for churches and public buildings, from it St. Paul's Cathedral (finished about 1700), Goldsmith's Hall, the west towers of Westminster Abbey, the Eddystone Lighthouse, and other prominent structures in England, being built. Aspdin gave the name "Portland" to his cement because of the resemblance in appearance between the artificial stone made from it, and the natural stone derived from these quarries.

Radford's Cyclopedia of Construction

Carpentry, Building *and* Architecture

A General Reference Work on

MODERN BUILDING MATERIALS AND METHODS AND THEIR PRACTICAL APPLICATION TO ALL FORMS OF CONSTRUCTION IN WOOD, STONE, BRICK, STEEL, AND CONCRETE; INCLUDING ALSO SUCH ALLIED BRANCHES OF THE STRUCTURAL FIELD AS HEATING AND VENTILATING, PLUMBING, ELECTRIC WIRING, PAINTING, CONTRACTS, SPECIFICATIONS, ESTIMATING, STRUCTURAL DRAFTING, ETC.

Based on the Practical Experience of a
LARGE STAFF OF EXPERTS IN ACTUAL CONSTRUCTION WORK

Illustrated

TWELVE VOLUMES

THE RADFORD ARCHITECTURAL COMPANY
CHICAGO, ILL.

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No 1

Radford's Cyclopedia of Construction

Prepared under the Supervision of

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Bibliography of Construction

BEING A SELECTED LIST OF STANDARD WORKS COVERING VARIOUS PORTIONS OF THE GENERAL FIELD OF CONSTRUCTION

In addition to the vast store of up-to-date practical information never before published, the editors have embodied in the Cyclopedia of Construction the cream of the world's best literature in this field, giving in condensed form the substance of everything essential in the experience of the past to enable the worker of the present to meet every problem likely to be met with under the conditions of ordinary practice.

For the sake, however, of those who may be interested in pursuing further study along various special lines, we furnish a list of important works that have appeared covering different portions of the field.

In this connection, the editors wish to express their thanks to American manufacturers and dealers in the machinery and materials of construction, as well as to proprietors and patentees of various special mechanical devices and processes, for valuable data, illustrations and suggestions.

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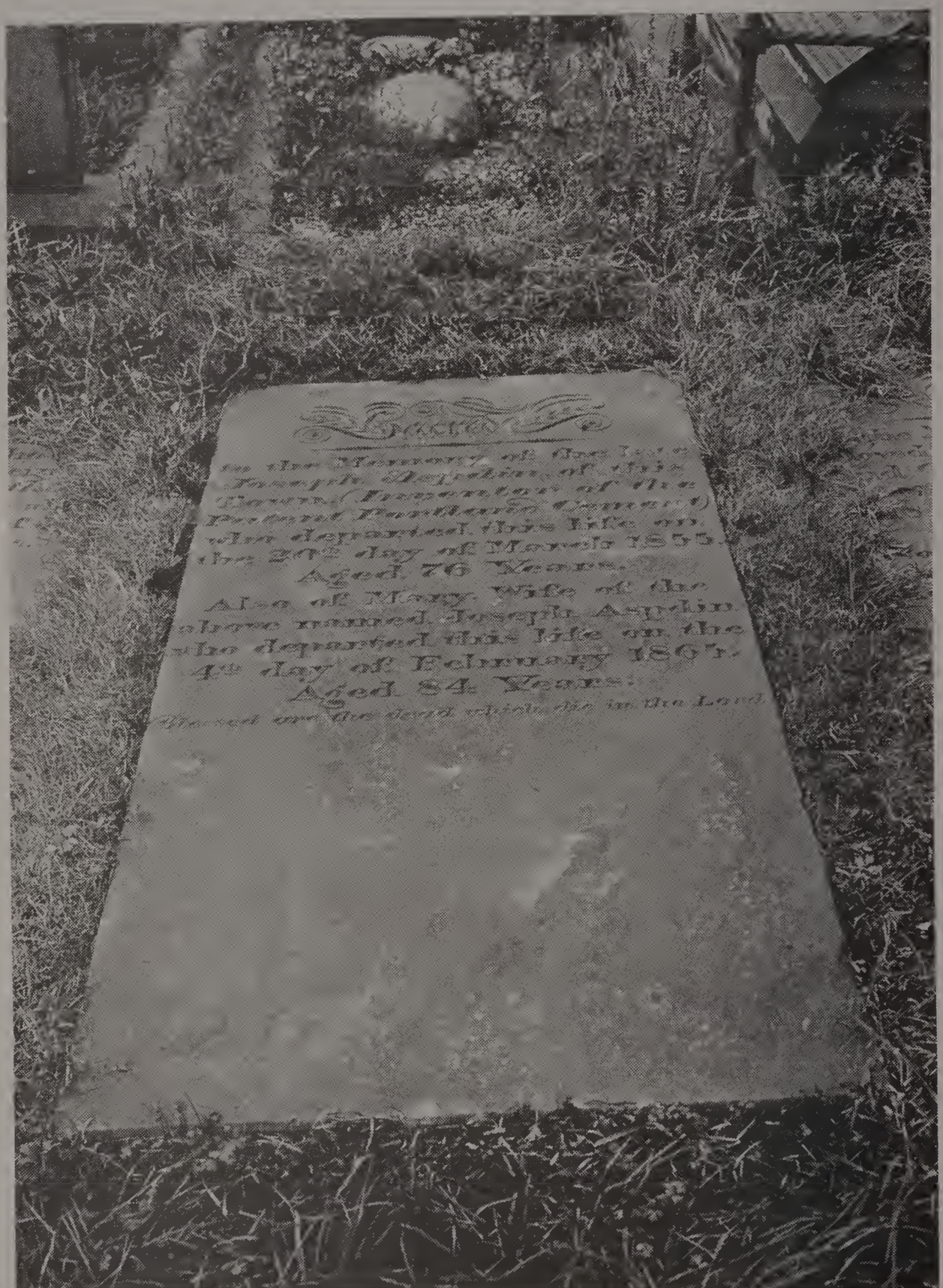

GRAVE OF JOSEPH ASPDIN, INVENTOR OF PORTLAND CEMENT.

In the graveyard of St. John's Church, Wakefield, England.

Preface

THE Building Industry, in its various branches, is more closely identified than any other with the marvelous engineering progress of the present day and the untold possibilities of the future. To put all classes of workers in familiar touch with modern methods of construction and the latest advances in this great field, and to bring to them in a form easily available for practical use the best fruits of the highest technical training and achievement, is the service which the CYCLOPEDIA OF CONSTRUCTION aims to render.

The work is pre-eminently a product of practical experience, designed for practical workers. It is based on the idea that even in the larger problems of engineering construction, it is not now necessary for the ordinary worker in concrete, or steel, or any other form of material, to attempt the impracticable task of exploring all the highways and byways where the trained engineer or technical expert finds himself at home. The theories have been worked out; the tests and calculations have been made; observations have been recorded in thousands of instances of actual construction; and the results thus accumulated form a vast treasure of labor-saving information which is now available in the shape of practical working rules, tables, instructions, etc., covering every phase of every construction problem likely to be met with in ordinary experience. This is perhaps most apparent in the sections on *Cement and Concrete Construction, Plain and Reinforced.* To this subject, on account of its supreme importance as a structural factor of the present day, three entire volumes are devoted, embodying the cream of all the valuable information which engineers have gathered up to date. Much of this practical information now presented in this Cyclopedia, has never before been published in any form. By its use,

anyone is enabled to take advantage of the vast labors of others, and to bring to bear on any problem confronting him the results of the widest experience and the highest skill.

The keynote of the Cyclopedia is found in the emphasis constantly laid on the *practical* as distinguished from the *theoretical* form of treatment, in its total avoidance of the complicated formulas of higher mathematics, and in its reduction of all technical subjects to terms of the simplest and clearest English. Throughout the pages devoted to Steel Construction, for example, the mathematics of the subject have been eliminated to such an extent that *the reader will not find a single instance where even a square root sign has been used.*

In addition to the larger problems of engineering and building construction, one entire volume, as well as many chapters scattered through the work, is devoted to those smaller constructions that are of special interest to the teacher or student of manual training or the home shop worker of a mechanical turn of mind.

Inasmuch as a wider knowledge and a more intelligent grasp of the fundamental principles of construction and design will tend to greater efficiency on the part of workingmen, and to greater economy in production, the purpose of the CYCLOPEDIA OF CONSTRUCTION is one which will appeal strongly, not only to the men themselves, but also to the architectural and engineering fraternity as a whole.

The authors of the various sections are all men of wide experience whose recognized standing is a guarantee of reliability and practical thoroughness.

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OLDEST PORTLAND CEMENT PLANT IN THE WORLD.

Built about 1835 by Joseph Aspdin, the inventor of Portland cement, on Ings Road, Wakefield. Here Mr. Aspdin carried on the manufacture of cement until his death in 1855. Part of one of the old kilns can be seen at the left.

Cement Construction

THE DAWNING AGE OF CEMENT

Concrete has come to be a dominating factor in the building world. Its invasion of the modern structural field, and triumphal progress therein, have already wrought a revolution; and its present widespread and rapidly increasing application to construction work of all kinds is the marvel even of this age of wonderful engineering achievement.

When, not many years ago, the steel-frame structure supplanted the historic masonry and timber, it worked a far-reaching transformation in building methods and materials, which was soon reflected in the external appearance as well as internal arrangement and details of new structures of almost every class. The sky-lines of cities and towns assumed new forms; and especially in the larger industrial centers, the very face of things was changed.

With the advent of a true Portland cement concrete—the handmaid of steel—still another and greater era of structural and industrial evolution was ushered in. Nothing in all the wonderful annals of American industrial development has ever equaled the expansion that has

characterized the Portland cement industry during the period since the year 1898. There are in fact many who, in view of the marvelous growth of cement manufacturing in America during these opening years of the twentieth century, and the wonderful versatility of this new structural agent, as shown by innumerable examples of its application to all kinds and grades of construction, are already proclaiming that the **Age of Cement** is upon us. Just as in the manufacturing world the successive eras of power development can be traced through the stages of human labor, water power, and steam power, to the present dawning age of electrical power, so, in the building world—we are told—the claims of wood and stone and brick and tile and iron and steel have now to adjust themselves to the urgent demands for recognition of concrete as a structural factor which is not only capable of supplementing them to advantage, but in many respects far surpasses them all.

In any country subject to rigorous climatic conditions such as prevail in North America, with its excessive changes of temperature and humidity, no natural building material exposed to the elements will withstand the ravages of time. Wood, being organic, is peculiarly responsive to the disintegrating activity of natural agencies, and, unless carefully protected from exposure thereto, is very rapid in its decomposition. Under the atmospheric influences of this climate, all grades of sandstone will in

time crumble back to mother earth; marble is still less enduring; and even the so-called "everlasting" granite is similarly limited in its life. Steel is subject to oxidation or rust from the combined action of carbon dioxide and water or the direct action of atmospheric oxygen, and to still more rapid chemical corrosion from the action of sulphurous and other noxious acid gases and liquids; and it must therefore be given the closest attention in the application of protective paints or other coverings to insure any degree of permanence.

Among building materials, concrete stands out alone as the one which can truly be called "permanent," and which has at the same time the quality of progressive and accumulative strength. It is this characteristic of **accumulative strength**—a strength increasing with the lapse of time—which more than anything else gives concrete its advantage over other materials in engineering and building construction. Under conditions of exposure that in the case of other building materials would accelerate the natural tendencies to decay and final collapse, concrete displays higher and higher powers of resistance, the action of the elements only adding hardness and strength as time goes on.

In addition, however, to the marvelous durability of concrete under trying conditions—which is, perhaps, its most striking feature—no other material now used in construction can be said to meet so successfully the combined

requirements of versatility in useful application, adaptability to varying structural conditions and combinations, simplicity combined with dignity and stability of appearance, harmonious adjustment to varying environment, cleanliness and hygienic value, and—last, but not least—economy of cost.

No progressive architect, engineer, contractor, or builder can in these days ignore the claims of concrete as a factor of supreme importance to be reckoned with in the general field of construction. In spite of early unfortunate experiences with natural cement, and more recent instances of actual failure—which have been traceable in every case to ignorance or criminal carelessness—concrete has irresistibly forged its way to general acceptance; has triumphantly risen above prejudice and doubt; and, by its own intrinsic merits, has finally won for itself an assured place as an instrumentality of twentieth century progress whose possibilities when realized may dwarf the dreams of the wildest imagination. Stronger and more durable than any natural stone, unaffected by fire or moisture, capable of adaptation to any position or condition, workable by unskilled labor, lending itself easily to any form of ornamentation, vermin-proof, cleanly, and comparatively inexpensive, it ranks among the foremost of the valuable gifts to mankind from the treasure-house of modern scientific and technical research.

A widespread popular knowledge of the nature and possibilities of concrete, the principles of its composition, and the rules of its intelligent use, will react beneficially in a thousand ways upon the life of the community. It will immeasurably increase the facilities of industry and commerce; it will minister to social conveniences and the education of public and private taste; it will make better homes, better municipalities, and a more progressive citizenship. That such knowledge is absolutely indispensable for the efficient working equipment of the modern builder goes without saying.

HISTORICAL SKETCH

No one knows when, where, or by whom concrete was invented or first employed. Its use as a material of construction dates back to the dim antiquity of prehistoric times, and examples of the ancient craft have come down to us with practically undiminished strength which have withstood the bombardment of nature's forces through all the centuries. Orpheus himself, whose lyric strains animated the very stones of which the walls of Thebes were built, may, for all we know, have been merely a skilled worker in concrete. Certain it is, however, that long before the dawn of authentic history, at a period back beyond the prying curiosity of scientific research, and while the earth was still young, people lived who knew a great deal about ce-

ment and its adaptability to the various needs of construction, as well as its wonderful powers of resistance to the disruptive action of natural forces.

The ancient Egyptians understood the use of hydraulic cement. It has been proved that in some of the marvelous constructions which still endure as monuments of their engineering skill, they used a porous lava possessing hydraulic properties and containing the basic element necessary to the making of cement somewhat similar to the Portland cement of the present day. Many of the sarcophagi in which they placed their dead were made of artificial stone. The majestic Pyramids which for over 4,000 years have reared their stupendous forms above the desert, and which still tranquilly laugh defiance at the ravages of time, were built in part of concrete. It is now generally conceded that in the construction of their upper tiers, at least, concrete was the material employed; and the massive blocks of stone that have baffled past ages by the mystery of their transportation to such elevations were probably borne to their destination by the pailful, and formed directly in place. Evidence that these blocks are of man's formation is found in the fact that breakages in some of them have revealed small pieces of wood embedded in the mass.

The Romans constructed many miles of highways and walls and aqueducts from hydraulic cements, which they also used to some extent

in the building of their residences and temples; and many examples of their work still extant not only bear witness to the high standard of civilization attained under the ancient Empire, but also afford unquestionable evidence of the permanent character of the material composing them.

The word "Concrete" is itself of Latin origin, meaning "grown together" ("con," together; and "crescere," to grow), and implies a body formed by the coalition of separate particles into a solid mass.

Roadbeds of concrete resounded to the thundering tread of the Roman legions as they went out to or returned from their campaigns of world-wide conquest. The famous Appian Way, over which the Apostle Paul entered Rome, as described in the Book of Acts in Holy Writ, was underlaid with cement concrete and topped with paving stones. The latter have been worn away, but the concrete is still intact, just as when the Romans laid it. This was the oldest of the Roman highways, having been started by Appius Claudius Caius about the third century before the Christian era. It extended from Rome to Capua, and later was built to Tarentum and Brundisium, in far Southern Italy. The aqueducts which supplied the imperial city with water were built without reinforcement, and are still in almost perfect condition. The cement lining of the Pont du Gard at Nismes, in Southern France, a Roman aqueduct built in the first cen-

tury A. D., is still hard and smooth as when first put in place. The pools of King Solomon, nine miles from Jerusalem, were built wholly of concrete, and still furnish water for the city. Many residences of the Roman nobles were constructed of concrete unfaced by brick or stone; and wood framing was used in casting the walls, in much the same manner as wooden forms are used in concrete construction to-day. The Colosseum was built on piers and foundations of concrete; and Professor Middleton, in his work on "Ancient Rome," tells us that the entire upper floor of the Antrium Vesta was formed of one great slab of concrete fourteen inches thick and having a span of twenty feet, supported on edges, but having no intermediate supports. The Pantheon of Rome, a circular temple originally dedicated about the time of Christ, in the reign of Augustus, has a dome 142 feet in diameter, constructed mainly of concrete, and still in perfect condition after 1900 years of service. The Aurelian wall about the city, over ten miles in length, still standing, was built of the same material. An English writer has said: "In strength and durability, no masonry, however hard the stone or large the blocks, could ever equal these Roman walls of concrete, for each wall was one perfect coherent mass, and could be destroyed only by a laborious process like that of quarrying hard stone from its natural bed." In the recent construction of a tunnel under part of the old city of London, England,

the workmen uncovered Roman cement which had been placed over 800 years before, so hard that it turned the edges of the hardest cold steel chisels.

Over other widely scattered portions of the earth, similar evidences are found that the early races were familiar with the constructive use of cement. In Spain and other Old World countries are found abundant examples of the ancient use of concrete in forms that have survived the ravages of time and the elements. The lookout towers of Ireland, supposed to have been built by the Druids more than a thousand years ago, are made of hydraulic cement concrete, cylindrical in form, about six feet in diameter, and 100 feet high. Some years ago one of these towers was undermined and overturned. In its fall, the shock of the huge mass was so great that the shaft sank into the ground to the depth of one-half its diameter for its entire length; yet not the slightest fracture occurred—a fact which demonstrates not only the strength but the elasticity of concrete. Had the shaft been a monolith (that is, one solid piece) of even the best quality of natural granite, the shock of such a fall would have reduced it to fragments.

A similar story as to the early use of concrete might also be written of the vanished races of the New World. The Peruvian builders in the days of the Incas employed concrete, impelled probably by the necessity of adopting a form of construction that would withstand earthquakes

and volcanic tremors. Some of their structures, though built many centuries ago, have endured to the present time. And even in our own North America, the use of this most versatile of plastic materials of construction antedates all historic or prehistoric records written in less enduring form. Twenty miles northeast of the City of Mexico are remains of a former but now vanished civilization, in the shape of pyramids of masonry that were built partly, if not entirely, of concrete. And ethnologists and antiquarians tell us that as far back as eleven thousand years ago, while the slow-working geological forces had not yet moulded the face of this continent to its present contour, the remarkable race of men known as the Mound Builders, along what are now the edges of the Ohio valley, were accustomed to boil salt water in kettles of artificial stone. And in the manufacture of their pottery, specimens of which are the most enduring mementos of their intelligence, they used as the cementing material carbonate of lime—a medium used for a similar purpose to the present day.

In one sense, therefore, concrete can lay no claim to novelty, being a return to principles once well known if less perfectly understood than now, but for a long time lost sight of or forgotten. It is not to be supposed, however, that in quality of material or in methods and appliances of construction the early workers in concrete attained anything like the high standards

of technical accuracy that characterize the manufacture of cement and its use in the various forms of concrete construction at the present day. The ancient skill which had been developed in the making and working of concrete appears for many hundreds of years to have become a "lost art." As the empires gradually went to pieces through internal decay, and the world stumbled on toward that dark period of utter standstill known as the Middle Ages, when the lamp of progress flickered but faintly in the cells of monasteries, we find that even in the elaborate cathedrals erected during this period the use of hydraulic mortars had given way to that of fat lime and silt mortars. These ingredients in time became inert powders devoid of strength and hardness, which necessitated constant watchfulness and costly bracing and repairs to keep the structures erect.

About the beginning of the eighteenth century, there came a revival in the demand for hydraulic mortars, which was met by supplies of Pozzuolana from Italy, or of the low-grade natural cement known as "trass," from Germany. In the erection of the Eddystone Light, about 1757, Smeaton developed a form of natural hydraulic cement, after experimenting on limestones containing different proportions of clay, and demonstrated the practical importance of chemical analysis in cement making.

With the discovery, however, of true Portland cement, the inauguration of accurate physi-

cal and chemical tests, and, in particular, the combination of concrete with reinforcing members, and analysis of the principles of constructive design, an entirely new era of development was ushered in—one distinctively modern and without analogy or precedent.

Development of the Portland Cement Industry. Notwithstanding its great powers of endurance, the concrete employed by the Romans was far inferior to present-day standards. That used in constructing the dome of the Pantheon, for example, was made by mixing broken stone and coarse gravel with a cement consisting of a mixture of slaked lime and volcanic ash. This cement was not a Portland cement, but closely resembles the Pozzuolan cement still produced in small quantities in Italy and other countries of Europe, which is manufactured by mixing volcanic lava (a natural product) and slaked lime, the resulting mass forming a rather weak hydraulic cementing compound without requiring the agency of heating.

Portland cement, on the other hand, is wholly an artificial product, made by calcining or burning a finely ground and carefully proportioned mixture of calcareous (limey) matter with an argillaceous (clayey) or siliceous substance (sand, quartz, or slag) to the point of incipient fusion, and grinding the resulting clinker to an impalpable powder, to which in some cases a small percentage of gypsum or other special ingredient is added.

Although Portland cement now far surpasses all other kinds of cement in structural importance and in extent of use, natural and slag cements still figure to some extent in construction work. The difference in composition, strength, and lasting qualities, however, is great.

The first cements manufactured in modern times were made in England. As early as 1790, one Joseph Parker made a cement by burning lumps of chalky clay stones and finely pulverizing the clinker. This he called "Roman cement," either because it resembled the cement used by the Romans in its property of setting under water, or because of its similarity in color to the lavas found in the vicinity of Rome.

It is, however, to Joseph Aspdin, a brickmason of Leeds, that the credit of originating the first **Portland Cement** is due, and he is therefore generally recognized as the father of the modern Portland cement industry. After experimenting for some years along the lines indicated by Parker, Aspdin produced a cement by mixing pulverized limestone with clay in certain proportions, calcining in kilns, and grinding very fine. This cement he named "Portland" because of its close resemblance in color to the famous stone quarried on the Isle of Portland in the English Channel, from which St. Paul's Cathedral, the Eddystone Lighthouse of Smeaton, and other prominent structures in England were built.

In 1824 Aspdin obtained a patent on his hy-

draulic cement. At this time, however, and for years thereafter, nothing was known of the proper proportioning of calcareous to argillaceous matter, or of the temperature necessary to insure a good product. Many experiments were made by English and French engineers in an endeavor to produce a cement that would command the attention of builders, but no permanent results of value were obtained. It was reserved for a German chemist, in 1828, to formulate the first theory of the action of ingredients and their proper combining proportions to make a true Portland cement. Without this knowledge, the securing of reliable material could never be depended upon. Improvements in standard were from time to time effected. Progress, however, was slow; and although the manufacture of Portland cement had been begun in England in 1825 or 1827, it was not until the middle of the century that this cement secured any wide recognition of its merits as a material of construction. In France, its manufacture was begun in 1846; and in Germany, at Stettin, in 1855; but it was not until 1860 that any considerable quantity was made for the general market in England or on the Continent, and even then but very little was made for exportation.

Portland cement was first brought to the United States in 1865; and during the following decade considerable quantities of the foreign product were imported, constituting the greater

portion of such cement used in this country by architects and engineers. In the late seventies, however, the domestic product began to come into competition with the foreign article, and American Portland cement has now almost entirely displaced that of foreign manufacture.

Thus, it was not until some years after the close of the Civil War that the great Portland cement industry in the United States had its beginning. For half a century prior to that time, natural cement—the first kind of cement manufactured in the United States—had practically a monopoly of construction work in this country. Its manufacture had been begun in 1818 by Canvass White, who secured a patent for a Roman cement made from natural rock; and this material was used in the original masonry work on the Erie canal.

The first Portland cement manufactured in the United States was made at Coplay, Pa., in 1872, by David O. Saylor, who exhibited his product at the Centennial Exhibition in Philadelphia in 1876. This was the small beginning of the present enormous American Portland cement industry, whose later growth has in many respects been unprecedented in the history of American industrial development. Not, however, until twenty years or more had passed, did the industry in this country begin to show any very substantial increase or tendency to rise. Up to 1880, in fact, only six plants for the manufacture of Portland cement had been established

in the United States—in Pennsylvania, New York, Maine, Indiana, and Michigan—and the entire American output aggregated a total of only 82,000 barrels. Not only were American methods of manufacture defective as compared with foreign standards, but at that time reinforced concrete was unknown, and the value and various adaptabilities of Portland cement concrete as a structural material were not dreamed of. Natural cement had almost the entire field to itself; and concrete, when it was used at all, was confined almost wholly to foundation and underground work. The slow progress of the Portland cement industry in America during these early days can be seen from a glance at Table I, which gives statistics of production in various years between 1880 and 1895.

TABLE I

Production of Portland Cement in the United States

Year	Amount Produced	Year	Amount Produced
1880	42,000 barrels	1892	547,400 barrels
1882	82,000 "	1893	590,652 "
1885	150,000 "	1894	798,757 "
1890	335,500 "	1895	990,324 "
1891	454,813 "	.....	.....

It was not until 1896 that the annual domestic production passed the million barrel mark.

The general commercial application of Portland cement concrete to construction work may be said to date from 1895. It had previously attained wide use in foundations, and at this time its development was beginning for such struc-

DAVID O. SAYLOR.

In 1872, at Coplay, Pa., he manufactured the first Portland cement made in the United States. See Page 15.

KILNS AT COPLAY, PA., IN WHICH PORTLAND CEMENT WAS FIRST MADE IN AMERICA, IN 1872, BY DAVID O. SAYLOR.

tures as dams, piers, breakwaters, sewers, and subways.

Several causes may be assigned for the comparatively slow early growth of the industry, followed by its later marvelous activity. In the first place, the American product, in the early days of the industry, was inferior to the imported German and other European makes. The latter were long looked upon as standard; and it was only after slow and tedious experimentation that the present improved American methods of manufacture were developed so as to produce a high-grade cement which, under the tests necessary for all structural materials, could be depended upon to give uniform and thoroughly reliable results. Moreover, the natural cement industry had attained a flourishing growth, and its competition had to be overcome. Again, the cost of imported Portland cement, on account of the tariff, continued high; and it was only with the gradual improvement in the processes of manufacture that the price asked for a domestic product of a grade equal to if not better than the foreign fell to a figure at which plain concrete could compete with stone masonry, or reinforced concrete with other constructive materials.

As a result, however, of this gradual improvement in quality and lowering in cost, domestic Portland cement has now almost entirely displaced the imported European product in American markets. Striking evidence of this is

found in the Portland cement exhibits which were made at the Columbian Exposition in Chicago in 1893, and at the Louisiana Purchase Exposition in St. Louis, Mo., in 1904. At the Chicago World's Fair of 1893, a very noticeable feature was the absence of any American Portland cement exhibit, while Germany had elaborate exhibits of this material. At St. Louis in 1904, these conditions were exactly reversed; and the conspicuous absence of foreign cement exhibits worthy of note served to emphasize the withdrawal of foreign cements from the American market. In 1893, more than four-fifths of all the Portland cement used in the United States was of foreign manufacture. Within the following decade the importations fell off about three-fourths. From one of the smallest, the United States has taken foremost rank among the largest Portland cement producing countries in the world. And records compiled from tests made by government and private engineers warrant the claim that the leading American brands of Portland cement are superior in quality to any of the foreign cements manufactured at the present day, this superiority being due to unsurpassed raw materials and the high grade of technical knowledge and skill embodied in American machinery and processes of manufacture.

In addition to improvement in quality and lowering of cost, a most important factor that contributed to the rapid expansion of the Port-

land cement industry in the United States was the application of concrete to steel structural work in fireproof building, and the subsequent development and widespread adoption of what is known as the **Reinforced Concrete** type of construction. These quickly created an unprecedented demand for good Portland cement.

Reinforced concrete is simply concrete in which steel has been imbedded to give additional strength and elasticity. Plain concrete has great compressive strength, and, when used in the form of pillars and posts, is capable of carrying heavy direct loads. It is weak, however, under tension—that is, when subjected to direct pull—and the principle underlying reinforced construction is simply that of incorporating steel members in a mass of concrete in such a manner as to enable the mass to withstand the tensile strains of transverse loads.

The general use of concrete on steel structures, about 1895, opened up a wide field of new opportunities for the use of cement. This field was enormously expanded by the general acceptance, about 1900, of reinforced concrete as a type of construction of practically unlimited possibilities. The subsequent history of the Portland cement industry in the United States has, in fact, coincided with that of reinforced concrete, one being but a reflex of the other in its unexampled growth. A detailed historical sketch of the development of reinforced concrete systems will be given later, under the head,

of "Reinforced Concrete." The subject is here referred to only in its bearings on the development of the Portland cement manufacturing industry.

The invention of the twisted bar for reinforcement was made in 1885 by Ernest L. Ransome, of San Francisco, and about 1890 came the introduction of expanded metal and the mesh systems of concrete construction, which allowed architects to retain their steel structures and use concrete for the filling and arch work between beams, in place of brickwork and terra-cotta. These methods enabled the architects to use concrete in a conservative manner, and to become acquainted with its structural properties, without abandoning the steel frame which constituted the main structural basis of their design. Between 1890 and 1895, the production of Portland cement progressed from 335,000 barrels to 990,000 barrels; and the lessons learned from the use of concrete in this type of combination with steel led to its adoption in a large number of projects originally planned for other material.

In 1897 and 1898 occurred a great shortage in structural steel, which gave directly a great additional stimulus to the adoption of reinforced concrete, and indirectly contributed enormously to the expansion of the Portland cement industry. Deliveries of shapes were so uncertain and remote that engineers throughout the country were at their wits' end to find ways and means

for fulfilling their designs, and they turned at once to reinforced concrete to help them out of their dilemma. European systems of reinforced concrete were introduced, and engineers generally began to study the subject from a scientific standpoint, with the result that by the year 1900 the steel concrete building was generally recognized as a structural possibility, and the adoption of reinforced concrete was considered for every conceivable kind of problem.

The statistics of Portland cement production during the years that immediately preceded and followed the opening of the new century, demonstrate in an astonishing way the increasing popularity of concrete and the confidence of the public in its properties. Between 1896 (when the production of American Portland cement first passed the million barrel mark) and 1908, the country's annual output increased fifty-fold. The 26 plants operating in 1896 grew in number during the following decade to over 100, representing an invested capital of more than $100,000,000. The phenomenal development of the industry will perhaps be best apparent from a glance at Table II, giving statistics of production from 1896 to 1908. See also page 318.

Analysis of these figures shows that the output of Portland cement in the United States has multiplied itself nearly ten times in as many years—a truly marvelous growth. The greatest single gain was in 1906, when the production increased over 11,000,000 barrels, and its valua-

TABLE II

Portland Cement Production in the United States

YEAR	AMOUNT PRODUCED	VALUATION
1896	1,543,023 barrels	
1897	2,677,775 "	
1898	3,692,284 "	
1899	5,652,266 "	$ 8,074,361
1900	8,482,020 "	9,280,525
1901	12,711,225 "	12,532,360
1902	17,230,644 "	20,864,078
1903	22,342,973 "	27,713,319
1904	26,505,881 "	23,335,119
1905	35,246,812 "	33,245,867
1906	46,463,424 "	51,240,652
1907	48,785,390 "	53,992,551
1908	50,000,000 " (approx.)	55,000,000 (approx.)

tion $17,000,000, over the year preceding. Within a period of five years ending in 1908, the production was more than doubled, the increase in valuation being proportionate. The output during the last four years alone of this period exceeded by nearly 75,000,000 barrels the entire production credited to the thirty years preceding; and the valuation of the product for the same period was over $70,000,000 in excess of the value of the entire production from 1870 to 1904. An examination of the statistics also shows a gradual downward trend in the prices of the finished product.

The prodigious growth of Portland cement manufacturing, especially during the past five years, has been unequaled elsewhere in the annals of American industrial development. No other industry has advanced with such mighty leaps and bounds in the same or a proportionate length of time.

But even these colossal figures show but little of the depth or extent of public interest that

has been aroused in the subject of cement and concrete construction. Even in periods of business depression, the demand for cement in the building trades has been such as to tax the capacities of the mills to their utmost. Portland cement has long since passed the stage where it was regarded as suitable only for the building of underground and under-water work. It has entered aggressively the field of general construction; and in spite of the fact that not all its structural applications and systems have yet been standardized, nor all its problems solved, it has abundantly "made good" in setting at rest all doubts as to its marvelous adaptabilities and fitness for constructive work in general. In the business and manufacturing districts and the residence streets of cities and towns, along the water-fronts of lake and ocean ports, along the railroad lines and country highways, at summer resorts, in rural villages and on the farm, structures of every size, shape, and style of adornment may now be seen in constantly increasing numbers—from the skyscraper to the one-story garage, from palatial residence to simple cottage or bungalow, from arched bridge to culvert and sidewalk and curb, from the great manufacturing plant to the simple shop, from barn to dog-kennel and hitching post—in whose construction cement has played a leading part. And when the constructive possibilities of this versatile material come to be fully realized by the vast army of the agricultural and so-called

"middle" classes—the substantial home-seekers and home-makers who constitute the backbone of our country—the output of the cement mills must show a still greater increase, which will dwarf even the present handsome figures of production.

In reviewing the progress of concrete in the Northwest, Mr. L. B. Roberts shows both a comprehensive grasp of present conditions and a prophetic insight into the future when he says:

"The new San Francisco is rising Phoenix-like out of the ashes of the old, a city of concrete. She is guarding the western portal of the nation against the dread bubonic plague, with Portland cement as her physician, and concrete her disinfectant. In a war of extermination against the rat and its flea, the prime carrier of disease, millions of yards of concrete have been laid. Wooden sidewalks, alley-ways, gutters, piers, and buildings are being torn down and replaced with concrete, disease and vermin-proof, under the supervision of United States engineers. And with the advent of the era of cement, the mortality rate in that city alone has decreased 50 per cent.

"The same precaution must in time be taken in New York, Savannah, Baltimore, and other ports of entry, as the plague seems to be slowly creeping northward, and with the completion of the Panama canal, the liability of seaports to infection will be increased two-fold.

"Portland cement made it possible to reconstruct the new Galveston on a grade many feet higher than the old city. Millions of barrels of it will figure in the Panama canal work alone, and the use of this material made possible New York City's splendid system of subways. London relies on it to regain some of her prestige as a seaport she has lost to Liverpool and Glasgow, and has

ordered in new piers of reinforced concrete all along the Thames.

"It is almost the sole building material used in the vast government reclamation projects in the arid West.

"Its cheapness, its beauty when finished, and its durability constantly recommend it to the thoughtful householder seeking to build a home and to gain the maximum of durability with the minimum of cost. Houses of concrete, at half the cost of a wooden dwelling, are a promise of the very near future, according to the results of experiments made by Edison and others.

"Ships of reinforced concrete, and Dreadnoughts protected with belt armor of concrete and steel, are a very real possibility of the future. Already canal boats have been made of concrete on a small scale, by a Missouri firm, and have been found to be perfectly satisfactory. Similar experiments are being made by the Italian Government. Experiments have been made with a belt armor made of reinforced concrete faced with steel, which indicate that it may prove a greater resistant to the impact of a projectile than even steel itself.

"Especially on the farm is Portland cement coming into more and more common use. With the increasing price of lumber, the farmer finds he can floor cow-barns, erect silos, and do other similar work more easily and more cheaply with Portland cement than with any other material. . . .

"It has even entered the field of the fine arts. White Portland cement, pure as the driven snow and white as the purest of Parian marble, at the same time possessing the strength and adamantine hardness of the gray cement, is a discovery of the past year (1908). It retains the finest impression from the mould, as faithfully as wax, and outlasts marble in the struggle with time and the elements. It promises largely to supplant decorative stone for the trimming of buildings, to take the place of plaster of Paris for the decoration of theaters; and rep-

licas of the world's most famous statues will be seen in the parks and on the driveways of the future, perpetuated in a material which will outlast the blocks of solid stone given form by the cunning hand of the sculptor. . .

"It is already the favorite building material on the plains of the Dakotas and Montana, where lumber is relatively scarce and prices high; and in the new boom towns, high schools, libraries, and public buildings are largely constructed of it.

"It is already looked on as the natural successor to lumber, and some there are who see in it the solution to some of the forestation problems. With the invention of steel moulds, the use of lumber even in forms for the concrete may be done away with.

"The future of the industry is assured. The exhaustion of raw material is so remote a possibility that it may be dispensed with. Limestones, clays, shales, and slate are found in large quantities in most of the States of the Union. Throughout New York, Pennsylvania, and most of the Eastern and Southern States, these minerals exist in inexhaustible quantities in close juxtaposition; while the south shore of the Great Lakes, especially through Ohio, Indiana, Illinois, and Michigan, is almost solidly underlain with limestone. Coal and labor are easily available in these districts as well, which accounts for the large production of Portland cement in these regions. The greater part of the country's output is produced in these States, though smaller plants are scattered about through the South and Middle West and the Coast States. . . .

"Throughout the Northwest, Portland cement is coming more and more into use for buildings, sidewalks, dams, railroad construction, and use in every shape and form. Already it has assumed a place of prime importance in building circles, and is increasing in importance day by day and year by year. Truly the era of cement has but begun—its future is assured."

Dictionary of Terms

Like every other branch of human activity, the concrete industry has developed a list of terms of special meaning. With the usage of these terms, the more common of which are given below, the student of cement and concrete should at the very outset make himself thoroughly familiar.

Activity—Manifestation of characteristic properties; the property of cement which causes it to set by undergoing chemical change on the addition of water.

Aggregates—The solid and relatively coarse ingredients which are bound together by cement in a mass of concrete. In the great majority of cases, the materials used as aggregates are mineral, comprising sand, gravel, crushed stone, furnace slag, cinders, etc., of varying degrees of fineness. In the form of concrete known as "pulp concrete," sawdust, an organic material, is used as an aggregate.

Chemically the aggregates are absolutely inert or inactive in the formation of concrete, playing only a physical part because of their presence as space fillers. Sand or other material fine enough to pass through a sieve of one-fourth-inch mesh, was formerly not classed as an "aggregate," this term being confined to the coarser grades of material. Inasmuch, however, as the function of the

sand is essentially the same, both physically and chemically, as that of the coarser ingredients, the later approved practice has come to include sand also among the "aggregates." The word is of Latin origin—from "ad" (to) and "grex" (a flock)—and means things collected together in a mass.

Angularity—The property of having edges or faces that meet sharply at angles, as distinguished from shapes that are oval or rounded.

Argillaceous—Consisting of, or containing, clay.

Armored Concrete—Same as Reinforced Concrete.

Artificial Stone—A term applied to concrete because of its resemblance in appearance to natural stone and its similar use as a material of construction; any stone made by mixing aggregates with adhesive material, allowed to harden, and used instead of natural stone.

Calcareous—Consisting of, or containing, calcium carbonate or carbonate of lime.

Calcining—Burning; subjecting to sufficient heat to cause partial chemical disintegration, or incipient or total fusion or vitrification.

Cement—The binding material which holds the aggregates together in concrete in a solid mass. Derived from Latin "caedere" (to cut), and signifies any substance used for making bodies adhere to each other, or binding together those which have been cut or broken apart, as mortar, glue, etc. The term

was originally applied to rough, unhewn blocks of stone used in construction; later, to marble chips used in making mortar; later, to mortar itself; and was finally extended to include any sort of plastic bonding material.

Center—A middle point, line, or plane, used, for example, in measuring the distance from one joist, beam, or column to another; the temporary wooden or metal supports used in the erection of arches or other superimposed or overlying constructive work.

Concrete—A building or constructive material, sometimes called "artificial stone," made by mixing together cementing material, aggregates, and water, in varying proportions depending on the desired strength and special intended use of the material. Derived from Latin "con" (together) and "crescere" (to grow), and means "grown together."

Concrete-Steel—Same as Reinforced Concrete.

Constancy of Volume—See Soundness.

Core—The mould used to form the hollowed-out part of a cement or concrete block.

Crazing—The checking or cracking of the surface of artificial stone, concrete, etc.

Crystallization—The setting of cement due to its chemical action on coming in contact with water.

Efflorescence—The white or grayish crust sometimes formed on the surface of brick, concrete, stone, etc., due to the leeching-out of soluble chemical salts.

Empirical—Based on practical experience as distinguished from refined scientific and theoretical calculations. Empirical rules, for example, are founded merely on the observed results of actual experience, while the theory underlying such rules may never yet have been formulated.

Erosion — Wearing away, as, for example, through the action of water, of the weather, etc.

Failure—Collapse, rupture, or fracture—as the failure of a beam or column.

Forms—Wooden or metal constructions set up temporarily for the purpose of holding concrete in shape and in place until it has set and has hardened sufficiently to be self-supporting.

Frost Line—The average level to which frost penetrates into the ground. It varies in different localities.

Fusion—Melting; usually applied only to melting of mineral substances which takes place at relatively high temperatures.

Gauging—Stirring or mixing.

Granolithic—Consisting of artificial stone of fine granular structure.

Green—Unripe, unseasoned, fresh. Applied to concrete, it signifies concrete which has not completely set.

Grout—Thin mortar.

Gypsum—A mineral consisting of the hydrous sulphate of calcium—that is, sulphate of lime

containing a considerable amount of water of crystallization. When the water is driven off by heat, the resulting product is "plaster of Paris."

Hardening—See Setting.

Hydration—A chemical change that takes place in combination with water or under the action of water.

Hydraulic—Active in the presence of, or under the influence of, water. Hydraulic lime and hydraulic cement, for example, are lime and cement that will set and harden under water. Derived from Greek "hudor" (water).

Incipient—Beginning to take place. Burning to "incipient" fusion, for example, means heating to a temperature at which fusion or melting of the material begins.

Keene's Cement—A special form of gypsum plaster whose properties depend on an admixture of a certain proportion of alum.

Monolith—A term applied to single-piece work, or walls built with concrete between frames. A word of Greek origin; its literal meaning is "one stone."

Mortar—A plastic mixture of lime, cement, plaster of Paris, or other material, with sand, water, hair, etc.; used for plastering or for binding together stone, brick, etc., in construction work.

Moulds—Frames used to shape concrete, plaster, or metal into various forms.

Pebble-Stone Finish—The finish given stucco or

plaster work by spreading small pebbles over the surface.

Plaster of Paris—Anhydrous sulphate of lime. Produced by calcining gypsum at a temperature sufficient to drive off the water of crystallization. Mixed with water, it forms a paste which quickly hardens, and is much used for casts, mouldings, hard plaster, stucco-work, etc. So called because first brought from a suburb of Paris.

Plastic—Capable of being moulded, formed, modeled, or spread, like mortar or paste.

Porous—The quality of possessing pores or minute voids.

Ramming—The pounding or beating of concrete to compress the mass and force out the superfluous water.

Reinforced or Reinforcing—To reinforce means to give additional strength to; in concrete work, it signifies the imbedding of steel members in a mass of concrete in such a way as to add to its strength and elasticity.

Retemper—To stir thoroughly again, so as to give a workable consistency; to regauge, as in stirring up mortar or concrete that has already begun to set.

Rubble—Rough, broken stone used in coarse masonry, or to fill between the facing courses of walls, or in making up the interior of massive stone or concrete work.

Screeds—Levels for guides and bearings for leveling and ruling off.

A NATURAL CEMENT MILL.

Works of the Utica (Ill.) Hydraulic Cement Company. The cement rock is carried up the incline and dumped directly into the upright kilns shown in the background at the right.

ENTRANCES TO NATURAL CEMENT ROCK QUARRY AT UTICA, ILLINOIS
The rock, sorted by hand, is carried by the electric railway directly to the kilns.

INTERIOR OF ONE OF THE CEMENT ROCK QUARRIES NEAR ROSENDALE, ULSTER COUNTY, NEW YORK.
From this rock the well-known "Rosendale" natural cement is made. See page 44.

DREDGING MARL FROM A LAKE BED.

Marl is a comparatively pure form of carbonate of lime, and is used by some plants as raw material giving the lime content of Portland cement.

Setting—Loss of plasticity; solidification from plastic state, due to crystallization of the cementing material. Takes place soon after mixing. To be distinguished from "hardening," which may continue for months or years after the "set" is complete.

Siliceous—Containing silica (quartz or sand), or partaking of its nature. Written also "Silicious."

Soakage—The absorption of water by hardened concrete, stone, brick, etc.

Soundness—Absence of tendency to cracking, swelling, shrinking, distortion, or disintegration under varying conditions of moisture and temperature; constancy of volume.

Stonette—A composition of Portland cement and fine aggregate.

Striking—Taking down and removing—as, for example, striking the centers or forms used in arch construction.

Stucco—Cement mortar or gypsum plaster, used in exterior finishing of buildings.

Subfoundation—The first layer of material placed in excavated ground for sidewalks, floors, etc.; usually it is cinders.

Tamping—The pounding of concrete to reduce voids and force the aggregates as closely together as possible into a compact mass.

Tensile Strength—The holding power or measure of adhesiveness of concrete or cement mortar; power to resist the action of forces tending to pull apart. Contrasted with **Com-**

pressive Strength, the power to resist crushing under direct pressure.

Trap Rock—A dark-colored igneous rock of great weight and strength, including basalt, feldspar, etc.

Treads and Risers—The tread is the horizontal part of a step. The riser is the vertical part.

Vitrify—To make glass-like, as vitrified clay, glazed surfaces, etc.; usually done by heating to fusion.

Voids—The air-spaces or interstices between the particles of aggregates.

Waterproofing—Rendering impervious to moisture. Accomplished either by special treatment of the concrete surface, or by mixing special solid or liquid compounds into the concrete mass before placing.

Wearing Surface—The top coat of cement and sand on walks, stairs, platforms, or verandas; any surface that is exposed to wear by being walked upon or brought into contact with outside forces.

Materials and Manufacture of Concrete

What Concrete Is. Concrete is an artificial or manufactured stone consisting of aggregates (sand, gravel, etc.) and cementing materials, mixed together with water. The ingredients to be used, as well as their proportions, vary with the kind of work for which the concrete is intended.

If a mixture could be made containing absolutely no voids or air-spaces—a mixture in which every part of the surface of every particle was covered by cement paste in intimate contact with it, and every intervening space between the particles completely filled with the cement paste —that mixture would be an **ideal mixture.** And provided the ingredients in this ideal mixture were of the kind and size and proportions best adapted to the work in view, and were of uniform good quality throughout, the resulting mass would be an **ideal concrete.**

A concrete which would be ideal for one purpose or location might not be at all suitable for another. The particular use that is to be made of the concrete is a factor which must always be considered in the selection and proportioning of its ingredients.

In practice it is impossible to attain the absolute perfection of these theoretical ideals. The air-spaces in concrete can be reduced in quan-

tity, but cannot be entirely eliminated. Even with the utmost practicable care and thoroughness in proportioning and mixing, and notwithstanding the use of enormous power in compressing the mass, some small, infinitesimal voids will still remain. The fallibility, also, of human perception and judgment in the choosing and testing of materials, and the greater or less imperfection that characterizes all devices and processes of man's making, will introduce at least some slight variation from the theoretical standards of absolute perfection. An ideal concrete is no more possible in actual practice than is an ideally perfect wood or stone or brick or steel or other structural material. We may know perfectly well what the ideal requirements are, but their complete realization will always be beyond us. The utmost that we can do is to approximate them more or less closely. They are the goal to be aimed at in all endeavor, and our work will be perfect only in proportion as we approach them. Nature herself affords us the only examples that are to be found of absolute perfection—in the handicraft of the Master Workman.

In spite, however, of theoretical limitations, and the fact that not all the problems of concrete have yet been finally worked out, nor all its details standardized, it can be said that the modern art of working in concrete has now reached such a stage of development that a degree of perfection sufficient for all practical purposes is quite

within the reach of everyone who will give the matter a little careful study.

For many years, concrete has been regarded as an ideal building material for the heavier and more massive kinds of work, such as aqueducts and viaducts, dams and piers, sewers, retaining walls, etc.; but it is only very recently that any great degree of attention has been given to its use in the smaller construction about the home and on the farm. Even here, however—among suburbanites and home-owners, villagers and farmers—it is now a subject of steadily growing interest and increased study, and is demonstrating its possibilities and advantages as a material of construction in many different ways.

The wonderful adaptability of concrete to various forms and combinations of construction is based on its property of changing from a plastic condition—in which it can be moulded to any shape or design—into a firm, rigid, rock-like mass, through the setting and hardening of the cement paste. No other building material that the world has ever known can compare with concrete in this respect. In addition, however, to this peculiar property, concrete possesses certain qualities which have irresistibly compelled the structural world to study carefully its alleged advantages as a substitute for wood, cut stone, and other old-time building materials, and which have naturally caused its claims to be looked upon with more or less favor. These qualities are its durability and accumulative

strength, its non-corrosion in moist places and freedom from rotting under any conditions, its cleanliness and sanitary value, its resistance to fire and the action of the elements, its protection of steel from corrosion, its deadening to sound, its ease of manipulation, and its moderate and steadily lowered cost as compared with the increasingly higher cost of lumber, due to the gradual exhaustion of our natural resources of forest wealth.

CEMENTING MATERIALS

In the making of concrete, the principal cementing materials used are **Common Lime, Hydraulic Lime, Natural Cement, Slag Cement** or **Pozzuolana** (sometimes spelled **Puzzolan Cement**), **Portland Cement**, and **Keene's Cement.**

Common Lime

The old-fashioned lime of commerce used in making mortar for ordinary plaster work, is also used to some extent in concrete work. The addition of a small percentage increases the smoothness and plasticity of wet concrete, and adds to the ease with which it is worked under the trowel.

Common lime is made by burning limestone in kilns. The limestone—which consists chiefly of calcium carbonate or carbonate of lime ($CaCO_3$)—on being subjected to intense heat, is partially decomposed. The carbonic acid gas (CO_2) which it contains is driven off, leaving

only the calcium oxide or oxide of lime (CaO). This is known as **quicklime** or **unslaked lime,** and is the form in which common lime is purchased on the market. A barrel of lime weighs 230 pounds net; and 60 cents a barrel may be quoted as an average price.

Before lime can be used, it must be **slaked**—that is, combined with water. Quicklime is soluble to some extent in **soft water**—that is, in water which does not already contain any large proportion of lime. In solution, it renders water **hard.**

The activity of quicklime is based on its great affinity for both water and carbonic acid. These ingredients it will absorb quite rapidly from the atmosphere, if left exposed; and in time it will become **air-slaked,** losing that power of becoming hard again which is its most valuable property as a material of construction. For this reason, in order to prevent deterioration, quicklime should be kept under cover, protected as much as possible from air currents, and, above all, must be kept dry.

When the lime is needed for use, it is slaked by adding water. Great heat is developed in the slaking process, and the volume of the lime is increased to about three times what it was before. An increase of about one-fourth in weight also occurs. From hard lumps, the mass is transformed into a fine white powder, which, on the addition of more water, becomes a smooth, **unctuous paste.** In slaking, the degree of heat

generated, and the volume of expansion, will vary somewhat with different limes, being the greater as the lime is purer, and thus affording a rough indication of the quality of the lime.

Lime made from marble is almost pure; but the product made from limestones will contain various impurities, such as silica, alumina, magnesia, etc. The presence of a certain proportion of these is not necessarily harmful. A lime may contain up to ten per cent of these foreign ingredients, and still be of "good quality." On the other hand, lime which has been allowed to deteriorate by air-slaking, or which contains too large a percentage of impurities, so that a proper slaking and expansion cannot be obtained, is said to be a "lean" or "poor" lime, as distinguished from a "fat" or "rich" lime. It may be so poor as to be entirely worthless except for fertilizing purposes.

In the course of time, if exposed to the atmosphere, a lime paste will harden by absorbing carbonic oxide from the air. The carbonate of lime is thereby formed, so that the process of the hardening of lime is in reality a return to approximately the original condition of the stone. It is upon this peculiar property of hardening under atmospheric action that the chief constructive value of lime depends. The hardening process may continue for years, penetrating deeper and deeper into the mass.

The very fact, however, that atmospheric action is essential, indicates the natural limita-

tions on the use of common lime as a material of construction. It is unsuited for work under water; here the air cannot reach it, and it will not harden. When exposed to the action of sea water, particularly, it will very rapidly disintegrate owing to the formation of soluble sulphates and aluminates. It is also unsuited for use in the interior of massive work where it will be buried at such depths as in effect to be sealed hermetically from the action of the carbonic oxide of the air. Even after standing many years, lime mortar in the interior of massive work has been found to be still soft.

Hydraulic Lime

Hydraulic lime, so called because of its property of setting when placed under water, is now but very little used in America. What little is employed in construction work is imported. It is made by calcining certain limestones which contain, besides carbonate of lime, certain proportions of clay or silica (ten to twenty per cent). Part of the carbonate of lime becomes ordinary quicklime; but other parts unite with the clay to form aluminate of lime, or with the silica to form silicate of lime.

Unlike the case of common lime, the slaking process is carried out **before** the product is marketed. A sufficient quantity of water to slake the quicklime completely and thus reduce the entire mass to a very fine powder (but not

enough water to affect the silicate or aluminate) is carefully added by sprinkling.

When the product, on being finally used, is thoroughly mixed with water, the aluminate or silicate appears to be dissolved, and, on drying out, becomes crystallized. To this cause, the setting of hydraulic lime is apparently due.

CEMENTS

Kinds of Cement. Most of the cement now employed in constructive work falls under one or the other of two main heads—**Natural Cement** and **Portland Cement,** the latter being much the more extensively used, especially where great strength and absolute reliability as to uniform quality are required. In some instances, the so-called **Pozzuolana** and **Artificial Slag Cements** are also used; and, for certain special locations and purposes, a special kind of cement known as **Keene's Cement** is preferred.

Natural Cement

Natural cement is so called because the raw material from which it is made is found in a **natural** state and is used just as it comes from the earth, requiring neither artificial proportioning nor the admixture of other ingredients.

In the case of the Portlands, on the other hand—for the different brands of Portland cement differ among themselves in chemical composition, and there is no general chemical formula for Portland cement—the raw material

is in every case an artificial mixture. Some natural ingredients, it is true, are used in the making of Portland cement; but the proportioning and mixing are always artificially done, and only after careful chemical and physical tests to determine exactly the proportions and the degree of fineness of grinding necessary for developing the qualities desired. A so-called "Natural Portland" is made in small quantities in England and on the European Continent, in those rare cases where limestone is found containing combinations of lime, silica, and alumina in the proportions approaching those which experience has shown to be desirable; but for best results, and to meet the large demand of the present day for a uniform and reliable product, a carefully calculated artificial mixture of ingredients is absolutely necessary. This point is well brought out in Taylor and Thompson's "Concrete, Plain and Reinforced," by S. B. Newberry, who says:

"If a deposit of stone containing exactly the right amount of clay, and of exactly uniform composition, could be found, Portland cement could be made from it, simply by burning and grinding. For good results, however, the composition of the raw material must be exact, and the proportion of carbonate of lime in it must not vary even by one per cent. No natural deposit of rock of exactly this correct and unvarying composition is known or likely ever to be found; therefore Portland cement is always made from an artificial mixture, usually, if free from organic matter, containing about 75 per cent carbonate of lime and 25 per cent clay."

Natural cements are made by calcining argillaceous (clayey) or magnesian limestones. The temperature required is considerably lower than that needed for the making of Portland cement. The resulting clinker is ground to a fine powder, which is then immediately ready for use.

Natural cements vary in color from light to dark gray, according to the character of the stone from which they are made. They are marketed under various names such as "Rosendale," "Utica," "Louisville," "Akron," "Milwaukee," "Fort Scott," etc., depending generally on the locality where the cement rock is found. The cement, for example, known as **Rosendale**—a name sometimes applied loosely to all natural cements—is made by burning magnesian limestone, of which very important deposits occur near the town of Rosendale in Ulster County, New York. After being quarried and sorted, the stone is heated in large kilns. The over-burned and under-burned portions are carefully discarded, and the properly burned portion is passed at once to crushers, where it is reduced to a fine powder, then being carefully screened and packed for shipment in either barrels or bags.

The so-called "Roman cement," first made in England toward the end of the eighteenth century, and still manufactured to some extent in that country and on the Continent, is one of the "natural" cements.

Owing to the fact that the chemical contents of the cement rock may differ greatly even in different parts of the same quarry, the strength of the product may show great variations on test; and it is only by careful selection of the desirable strata that a uniformity of quality can be insured. Much of the disfavor with which natural cements have been looked upon by engineers has been due to this uncertainty and variation in strength. In the case of Portland cement, on the contrary, a substantially absolute uniformity of composition and consequent reliability as to strength in any particular brand, are not only attainable, but are practically assured by the careful technical supervision exercised over all the processes and details of manufacture by the leading American Portland cement makers.

In strength, natural cement falls considerably below Portland. Its hydraulic activity, on the other hand, is considerably greater; that is, it sets much more quickly than Portland cement —which may or may not be an advantage, depending on the time available and whether a quick or slow setting is desirable. The setting of natural cement can be retarded, and thus regulated to some extent, by the addition of a small proportion of lime in mixing the mortar or concrete.

For use under sea water, a good quality of Rosendale cement seems better adapted than the ordinary Portland. The former is of con-

stant volume in sea water, probably due to the absence of free lime and to the presence of a larger amount of magnesia than can safely be used in Portland cement; while the latter has a tendency to expand or swell and disintegrate, probably because of the chemical action of the sulphates in the water upon the constituents of Portland cement, and the consequent formation of soluble salts.

Natural cement costs less than Portland, and for this reason is still used to a large extent in construction where no very great degree of tensile strength is required. It is well adapted, for example, for use in the interior of heavy masonry. The lower cost of natural cement as compared with Portland is explained by the fact that its raw material is wholly a natural product used just as it comes from the quarry, and in its manufacture a much lower temperature is required for burning than is needed for the making of Portland cement.

Natural cements will not carry so large a proportion of sand with good results as will Portland, and they require more water than the latter for proper hydration; they are more plastic, however, and work more smoothly under the trowel or other tools.

The Western natural cements, such as "Louisville" and "Akron," weigh 265 lbs. to the barrel; but "Rosendale" from New York or Pennsylvania weighs 300 lbs. to the barrel. Natural cements are thus lighter than Port-

lands, which weigh about 380 lbs. per barrel; and they are usually sold in cloth bags, three bags to the barrel, instead of four bags, as is the case with Portland cements.

For many years, as already noted, natural cement enjoyed a practical monopoly of the constructive field in concrete work. In recent years, however, the natural cement industry has shown a remarkable decline. This is readily explained by improvements in American machinery and by skilled technical supervision of the processes of manufacture, which have resulted in the production of absolutely reliable Portlands; by the greater adaptability of the latter to constructions requiring the utmost possible strength; and by the gradual lowering that has been effected in the cost of Portland cement. Portland cement is superseding natural almost all along the line. Statistics show that the manufacture and sale of natural cement, within the last five or six years, has fallen off from sixty to eighty per cent. In 1906, for example, of the total production of all kinds of cement, amounting to over 50,000,000 barrels, valued at over $54,000,000, only 3,935,275 barrels, valued at $2,362,140, consisted of natural cement; and 481,224 barrels, valued at $412,921, were Pozzuolana. The Portland cement industry, on the other hand, has expanded by leaps and bounds; and, as before intimated, notwithstanding its already unprecedented development, the future holds out the promise of still greater attain-

ments whose possibilities can as yet be but dimly foretold.

Slag Cement or Pozzuolana

The use of slag cement dates back to ancient times. The cement used by the Romans was made for the most part from a simple mixture of lime and volcanic lava. The lava first used for this purpose appears to have been obtained at Pozzuoli, a village lying near the base of the volcano Vesuvius. For this reason the name **Pozzuolana**—or, as it is very commonly spelled, **Puzzolan** cement—was first given to this form of cementing material, and has since been extended so as to include all forms of slag cement which are made without calcining.

In Italy and some other parts of Europe, Pozzuolana is still made from lava; but in America, **furnace slag** is used instead. This material is simply mixed mechanically and thoroughly with slaked lime. No burning is required, but the mixture is ground exceedingly fine.

In chemical composition, slag cement consists of a combination of silica and alumina, mixed with hydrated lime. Like Portland cement, natural cement, and hydraulic lime, it has the property of hardening under water; but in hardness and strength it falls far below the standard of true Portland cement. It is of a pinkish hue in color, and of lower specific gravity than Portland cement. It is not used to any

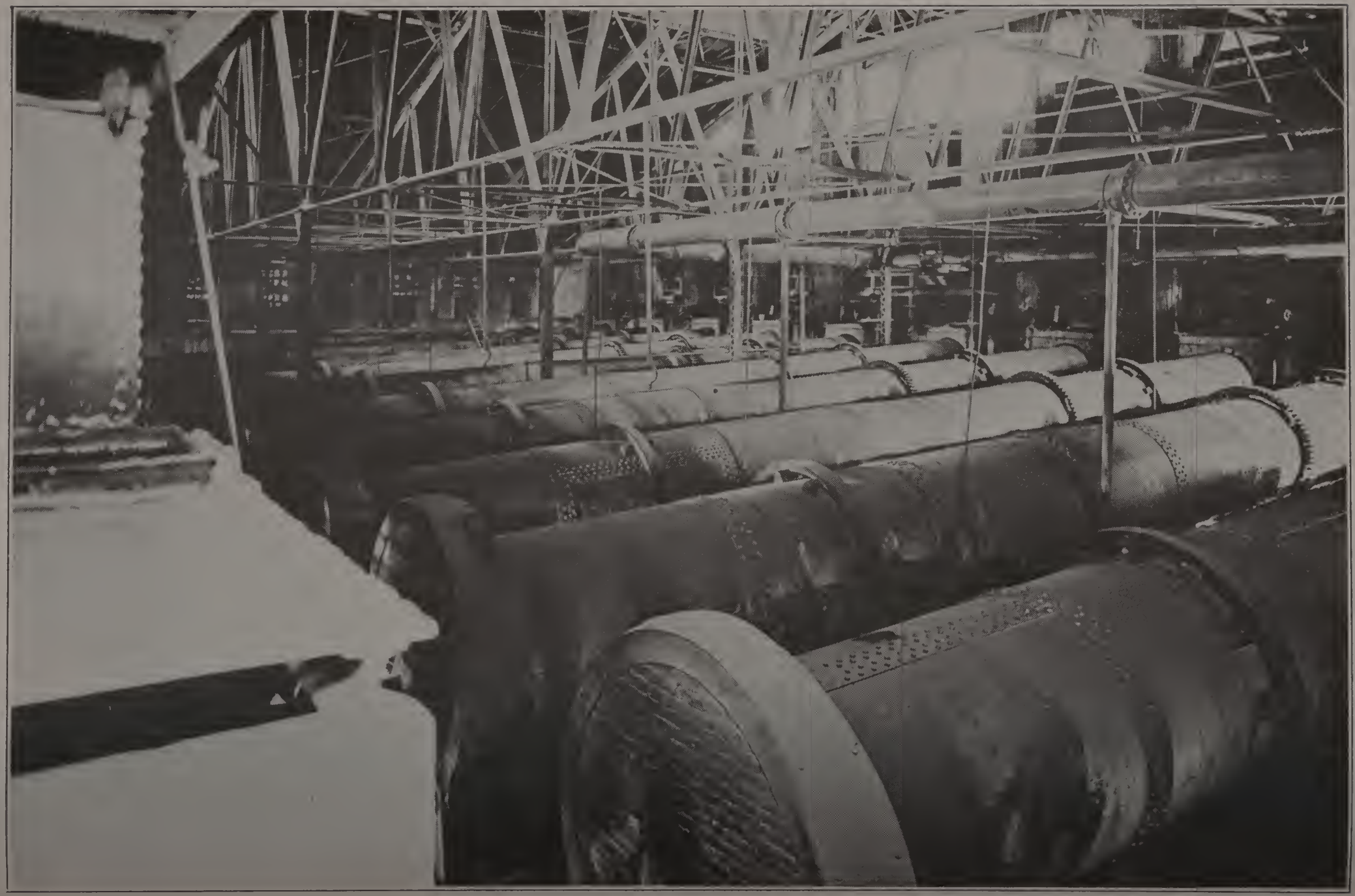
A TYPICAL EXAMPLE OF A SLATE QUARRY.

A GYPSUM QUARRY IN THE MIDDLE WEST.

In the manufacture of Portland cement, a small percentage of gypsum is generally added just before the final grinding, to regulate the activity of the product and prevent too quick setting.

ROTARY KILN FOR MANUFACTURE OF PORTLAND CEMENT.

Steel cylinder, lined with firebrick, is 125 feet long.



BATTERY OF ROTARY KILNS BURNING GROUND MIXTURE OF RAW INGREDIENTS TO CEMENT CLINKER.

great extent in building operations. It cannot be depended on in freezing weather, and is not well adapted for dry work which is to be left exposed above ground to the action of the atmosphere. Its principal use is for underground work and in moist locations. Sea water appears to affect it less than it does Portland cement; and for that reason slag cement is sometimes used instead of Portland in cases where large masses of masonry or concrete are to be deposited under sea water, and where great strength is not the prime consideration.

PORTLAND CEMENT

In 1908, Portland cement was manufactured in at least twenty-five of the forty-six States of the Union. The raw materials used by the different plants vary considerably, so that no absolutely universal rule can be laid down for the selection or proportioning of the ingredients from which Portland cement is made. It is equally impossible to give any exact formula for its chemical composition, since the latter, too, is found to vary through a considerable range. Nor, in fact, is it even possible to give a definition of Portland cement which will invariably afford an accurate guide as to its physical ingredients or chemical composition. These things are not secret mysteries; but they are variable factors, no two brands being exactly the same in these respects. Thus, Portland cement eludes all attempts to reduce it to the uniformity of a

positive chemical formula or universal standard of composition.

It is not to be supposed for a moment, however, that a true Portland cement is any uncertain quantity or unworthy of implicit confidence as a structural factor. Its composition may vary, and does vary; but that is immaterial. From the structural point of view, the important thing is that the cement, and the concrete made from it, shall meet certain requirements as to strength, durability, constancy of volume, fire resistance, etc.; and in these respects, not only can Portland cement be manufactured with such perfection as to conform to all the positive standards that experience has shown to be desirable; but in construction work—especially where failure would involve great destruction to property and possibly to human life—it should be the invariable practice to make assurance doubly sure by careful testing, to see that the particular brand of cement whose use is proposed does actually come up to standard requirements in every respect.

What Portland Cement Is. So far, then, as it is possible to give an accurate definition, Portland cement may be defined as any cement which, on being tested, will manifest the characteristic properties that engineers have agreed to associate with the name "Portland," and which will meet the requirements that have been accepted as standard. If, for example, from even such unpromising material as eggshells

and street sweepings, a product could be obtained which would pass all the standard tests, it would be fully entitled to be called a "Portland cement."

Raw Materials. As a matter of fact, however, the ingredients from which true Portland cements can be manufactured, although very widely distributed in nature, appear to include only a comparatively limited list. In the main, they comprise calcareous or limey materials, argillaceous and siliceous materials, and blast-furnace slag, with minor accessory materials added for the purpose of regulating the activity of the product.

The forms of calcareous matter generally used are three in number—**limestone, chalk,** and **marl**—each of which must contain the requisite amount of lime; for about sixty per cent, or nearly two-thirds by weight, of all Portland cement consists of this ingredient. Limestones are found almost everywhere. Chalk and marl are forms of limestone, usually of a purer calcium content than the ordinary "limestone" so called. Marl is a finely powdered substance usually found at the bottom of lakes or in swamps, having been deposited there by the action of water; and consists almost entirely of pure carbonate of lime. It is dredged out of its bed or mixed with water, and pumped into tanks for future use, being employed in what is known as the "wet process" of cement making.

Clay, shale, and **slate** are used for the silica, alumina, and iron contents of the cement; and **blast-furnace slag** is also used for this purpose.

In physical form, Portland cement is an exceedingly fine powder, ordinarily of a dull bluish or greenish gray tint, though brands of pure "white" Portland are now also made.

Manufacturing Processes. Portland cement is obtained by first grinding and mixing together, in carefully determined proportions, the principal raw ingredients, then heating the mixture to a temperature at which melting begins (2,000° to 4,000° F.), and finally grinding the resulting **cement clinker** to an impalpable powder, a small percentage (not over three per cent) of gypsum or other material being subsequently added in some instances, to retard the setting or otherwise regulate the activity of the product.

The degree of fineness to which the clinker is ground has an important bearing on the strength of the cement. The finer the cement, the higher the test it will stand, both in tension and in compression. The extreme degree of fineness considered necessary for the best results may be seen from the fact that in the case of one of the leading American brands of Portland cement, the manufacturers guarantee that 95 per cent of their product will pass through a sieve having 10,000 meshes to the square inch, and 80 per cent through a sieve having 40,000 meshes to the square inch.

In addition to the characteristic properties

developed under test, as explained later, a feature that distinguishes Portland from all other cements is the accurate and wholly artificial proportioning and mixing of its raw ingredients. All the Portland cement mills have chemists in charge of laboratories, who determine the proportions of the materials that are being used from day to day, and thereby maintain a standard of mixture as nearly perfect as possible.

Another distinguishing feature of Portland cement is the intense heat necessary in calcining the pulverized raw materials, as compared with the temperatures which are found sufficient in the manufacture of the so-called "natural" cements.

In the mixing of the materials for Portland cement, two processes are used—the **wet** and the **dry**—depending on the amount of water present. Where marl is the calcareous ingredient, the "wet" mix is almost invariably employed. In either case, the materials are first crushed and mixed, and then finely ground, whereupon they are ready to be passed to the calcining kilns.

The Rotary Kiln. In the early days of the Portland cement industry, a simple, vertical kiln like those used for lime burning was used. This type of kiln, however, while fairly efficient as to fuel cost, required too much labor, and the output was small. The result was the development of the **rotary** or **revolving kiln**, which

is the type of kiln universally used at the present day.

The rotary kiln was evolved only after much experiment. As at first perfected, it was applicable only to "dry" mixtures, and fuel oil and gas were the only fuels that could be used. Rotary kilns are now, however, used for calcining both "wet" and "dry" mixtures; and in many cases powdered coal, blown in by forced air-blast, is employed as fuel. In the making of "white" Portlands, an oil or gas flame is still used, in order to avoid staining the product.

The rotary kiln consists of a steel cylindrical tube, five to eight feet in diameter. It is lined, except at its upper end, with a highly resistant firebrick, to withstand both the high temperatures generated and the destructive action of the molten clinker. Its length, for "dry" materials, is 60 to 150 feet; and for "wet," 80 feet or longer. In its mounting, the tube is set with one end higher than the other, so as to give it a gentle incline—about one-half inch to the foot. It is mounted on geared bearings which revolve it slowly on its axis. The fire is applied at the lower end. The mixture of the raw materials is fed in at the upper end; is heated to the melting point (2,000° to 4,000° F.) as it passes slowly down the tube; and is discharged as cement clinker at the lower end, being then ready to pass to the final grinding.

It was the development of the rotary kiln that rendered possible the very great increase

in the annual production of Portland cement that has been recorded since the early nineties; and to it, also, in large measure, may be attributed that marked improvement in the quality of the product which has compelled the world to acknowledge that the leading brands of American-made Portland cement, in point of quality, are superior to all others manufactured at the present day.

While the fundamental processes in the manufacture of Portland cement are essentially the same for the various brands, there may be minor differences among the different plants in the details of machinery, methods of handling, etc., depending on the location and arrangement of the plant, the particular kind of raw material used, etc. "Atlas" cement, for example, is made from cement rock and limestone; "Berkshire Snow White," from white marble and clay; "Buckeye," from Maryland clay; "Chicago A A," from rock and clay; "Lehigh," from marl and limestone; "Universal," from limestone and granulated blast-furnace slag from the Bessemer furnaces of the Illinois Steel Company; "Vulcanite," from cement rock (Trenton limestone or argillaceous limestone) and carbonate of lime; etc.

A description of the working of a Portland cement plant—which, with minor differences of detail, may be considered as a typical example—is given by one of the leading American manufacturers as follows:

"Large bins approached by elevated tracks at one end of the raw material mill, provide the storage room for the raw material. From these bins, the limestone is fed directly into gyratory crushers, which prepare it for the driers, into which the stone then enters. The slag is also fed into separate driers, all of which are maintained at a sufficiently high temperature to drive off all the moisture. After passing through the driers, each of the raw materials is conveyed into separate revolving ball mills, where the rolling and impact of forged steel balls reduces them to extreme fineness. The two materials are then carried to separate hoppers, from which they are drawn off and properly proportioned by electrically operated weighing devices. The mixture of slag and limestone, already a powder, is then passed into the tube mills where flint pebbles rolling in a steel drum thoroughly mix it and complete the process of pulverization.

"The next step is the calcination of this raw mixture in rotary kilns. Leaving the rotary kilns, the clinker produced by the burning is dropped into storage pits, where it is cooled and cured. Electrically operated cranes then carry the clinker to the finishing mill, where it is passed through jaw crushers to Kent mills, and then over Newaygo separators. After the addition of a certain quantity of gypsum, which is done by means of an automatic device, the material again passes through the tube mills similar to those used in finishing the raw material. Being now ground to a specified degree of fineness, the cement passes on to a belt conveyor, and is distributed into the various bins of the storage house.

"The cement, in passing from the finishing mill into the storage house, is automatically sampled, from which samples the various tests for quality are made in the laboratory."

From the above descriptions of the raw materials and the processes of manufacture, the

reader will be able readily to grasp the full significance of the following "official" definitions of Portland cement:

As defined by the American Society for Testing Materials, Portland cement is:

"The finely pulverized product resulting from the calcination to incipient fusion, of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination."

As specified by the United States Government (Board of Engineers, U. S. A., "Professional Papers," No. 28), Portland cement is:

"The product obtained from the heating or calcining up to incipient fusion, of intimate mixtures, either natural or artificial, of argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination; and thereafter additions or substitutions, for the purpose only of regulating certain properties of technical importance, to be allowable to not exceeding 2 per cent of the calcined product."

It will be seen that no absolute standard for the chemical composition of Portland cement can be formulated. A good commercial Portland cement, however, will conform approximately to the following chemical analysis:

Lime (Ca O)—57 to 65 per cent.
Silica ($Si O_2$)—21 to 24 per cent.
Alumina ($Al_2 O_3$)—6 to 8 per cent.

Sulphuric acid, anhydrous (SO_3)—0.5 to 2 per cent.
Oxide of Iron ($Fe_2 O_3$)—2 to 4 per cent.
Magnesia (Mg O)—1 to 4 per cent.
Water and carbolic acid—1 to 3 per cent.
Sulphur, as sulphides—None.

A close study of the chemical constituents of Portland cement reveals the reason for the remarkable durability of the concrete produced from it. The products resulting from the hydration of a standard Portland cement are in no way responsive to the oxidizing and reducing gases of the air which are active in the rotting of wood or the corrosion of steel and metal structures. When hydration is complete, and the molecules have established normal equilibrium, the products represent compounds of the highest stability. If the cement is of poor quality, disintegration may result from some interior agency; but this is never manifest in a well-proportioned and well-manufactured product.

Portland cement is packed for shipment in paper bags, cloth sacks, or wooden barrels. The cloth sack gives the most conveniently handled package for the average user. It costs a little more than the others, but this is offset by a rebate allowed for the return of the empty sacks. The bags must be kept dry and untorn, and returned by freight exactly as directed by the cement company. Paper bags are easily torn, and cause a big percentage of loss, especially on small jobs where any carrying has to

be done. Barrels are too bulky to be handled easily, and are too large a unit for measuring.

The weight of the shipping units of cement varies slightly; but in general, a paper or cloth bag contains 95 lbs. of cement, and four such bags make a barrel of 380 lbs.

Storage of Cement. Since cement readily absorbs moisture from the atmosphere, becoming lumpy or even a solid mass—in which condition it is worthless and must be discarded—it **must be stored in a dry place.** If an attempt is made to break up lumpy cement and use it, it will be found to have lost most of its adhesive power and hardening qualities, and so to have lost the greater part of its strength and value as a building material.

In the store-room, the cement should not be piled directly on the floor. Blocks should be laid on the floor, and planks placed over them, thus providing a platform slightly raised above the store-room floor. On this platform, the cement should be piled, and a covering of canvas or roofing paper should be thrown over the pile.

If properly stored, where there is no absorption of moisture sufficient to harden it, Portland cement can be carried from one season to another without deterioration. Some makes, in fact, have shown improvement. Long storage of cement tends to retard its setting, though not preventing its ultimate acquisition of full hardness and strength.

Setting and Hardening. When cement is ready to be used, and is mixed with a sufficient amount of water to bring it to a paste, it soon loses its plastic nature, and finally reaches a point at which it can no longer be disturbed without producing a rupture. This change of condition is known as **setting**, and should be distinguished from the **hardening** of the mixture. Setting is usually complete within a few hours, whereas hardening may continue for months or even years. A further distinction is made between **initial setting** and **final setting.** The time required for setting will depend largely on atmospheric and weather conditions, as setting proceeds more slowly in cold weather than in warm. The initial set generally takes place within thirty minutes, and final setting within four to five hours.

General Requirements. The general requirements of a good Portland cement may be very briefly stated thus: The final set should take place within a few hours after mixing. The cement should have a certain tensile and compressive strength, and a considerable part of its ultimate strength should be developed within a few days. Age should bring no deterioration or loss of strength in the concrete made from the cement, but rather an increase of strength. And even under conditions of moisture and temperature far more severe than any that are ever likely to be met, the cement should demonstrate a quality of permanency; that is, the tendency

to shrink or swell or be distorted or disintegrate should be so small as to be a negligible quantity.

The possession or lack of these requisite qualifications on the part of any particular brand or shipment, can be determined only by a thorough testing.

Keene's Cement

Keene's cement is a special form of gypsum plaster which has certain unique and valuable properties. It is much harder than ordinary gypsum plaster, will take a good polish, and can be washed with damp cloths without injury. For these reasons it is often used for wainscoting, column coverings, casts, mouldings, etc., intended for places of unusual exposure, common gypsum plaster being hard enough for all ordinary conditions. Hydrated lime is often present in the American product, but imported Keene's cement is generally pure.

This form of cement is made by saturating lump gypsum which has been subjected to intense heat, in a solution of one part alum to thirteen parts water. The rock so treated is ground, then treated again with the same alum solution, and finally ground again.

CONCRETE AGGREGATES

While cement, in concrete construction, is a very important element, nevertheless the other materials with which it is combined, and the

manner of proportioning, mixing, and depositing them, are also factors of prime importance, and should be submitted to the same carefulness of inspection, preliminary testing, and intelligent supervision of competent authority as may be required of the cement itself.

The solid materials which are mixed with cement and water to form mortar and concrete, are known under the common name of **Aggregates.** The substances chiefly used as aggregates are sand, crushed stone, and gravel. The stone may range from hard trap rock and granites to the weaker and more porous varieties of sandstone, etc.; and the list of available materials includes also shells, slate, shale, cinders, slag, crushed lava, broken brick, metal filings, and—for "pulp" concrete—sawdust.

A fairly good concrete can be made with almost any mineral aggregate, **provided enough cement is used.** In order, however, to save cement, reduce cost, and at the same time secure the best results, it is exceedingly important that the concrete worker know how to select the best aggregates for the work in hand, and how to determine the proper proportions to use of fine and coarse ingredients.

Selecting Aggregates

In the first place, an aggregate for any kind of work should be **clean.** Dirt is a sign of weakness. Any foreign substance, such as mud or clay, forming a coating on the particles of the

aggregate, prevents the cement from coming into contact with the surface, and lowers the cohesive strength of the concrete, or its power to hold itself together. It may also seriously retard the setting. A loss of 15 to 20 per cent in strength may be caused by the use of a dirty aggregate.

Coarse aggregates can be cleaned by spreading them on an inclined plane, turning a hose on the pile, and allowing the water to carry away the impurities. Fine aggregates can also be cleaned in a similar way, by spreading on an inclined platform in a layer 3 or 4 inches deep, and washing gently with a ¾-inch hose from the high end of the platform. Pieces of board projecting up about 4 inches above the face of the platform, should be nailed around its edges to confine the sand, the water being allowed to flow over the top of the board nailed across the low end. A small quantity of clay or loam will not injure the sand, but any amount over 5 per cent should be washed out.

On a very small job, the sand may be cleaned by stirring up in water in pails or barrels, and pouring or drawing off the water while the dirt is still in suspension.

It may sometimes be advisable to use the aggregate that is nearest at hand, and to depend for results on an extra amount of cement. A natural bank of sand and gravel, for example, may be located near the work, giving an abundant supply of aggregate at a cost of very little

more than the labor required to get it out. If the structure is to be a small one or of comparatively slight importance—say, a culvert—and particularly if the cost of Portland cement is low, the above course is the proper one to follow. But in the case of large or important structures such as buildings and bridges, or where special products such as concrete blocks or brick are being manufactured, the aggregates and cement should be selected and proportioned with the greatest care, to insure uniformity and reliability of results.

In the selection of aggregates, it is well to bear in mind that the object is to make a mixture in which all the voids or spaces between the particles shall be filled. The voids in the stone or gravel should be filled by the sand, and the voids in the sand should be filled by the cement paste. This result is secured by varying the proportions of coarse and fine material. Since a perfect filling of the voids is rarely if ever attained, it is well to use a little more sand and a little more cement than would be just enough to fill them.

The volume of concrete will not be equal to the combined volumes of the cement and aggregates, but will be considerably less, because the finer particles hide themselves, as it were, in the spaces within the mass of the coarser particles. In this way, the pile of concrete resulting from a mixture of cement, sand, and gravel will be only slightly larger than the original pile of

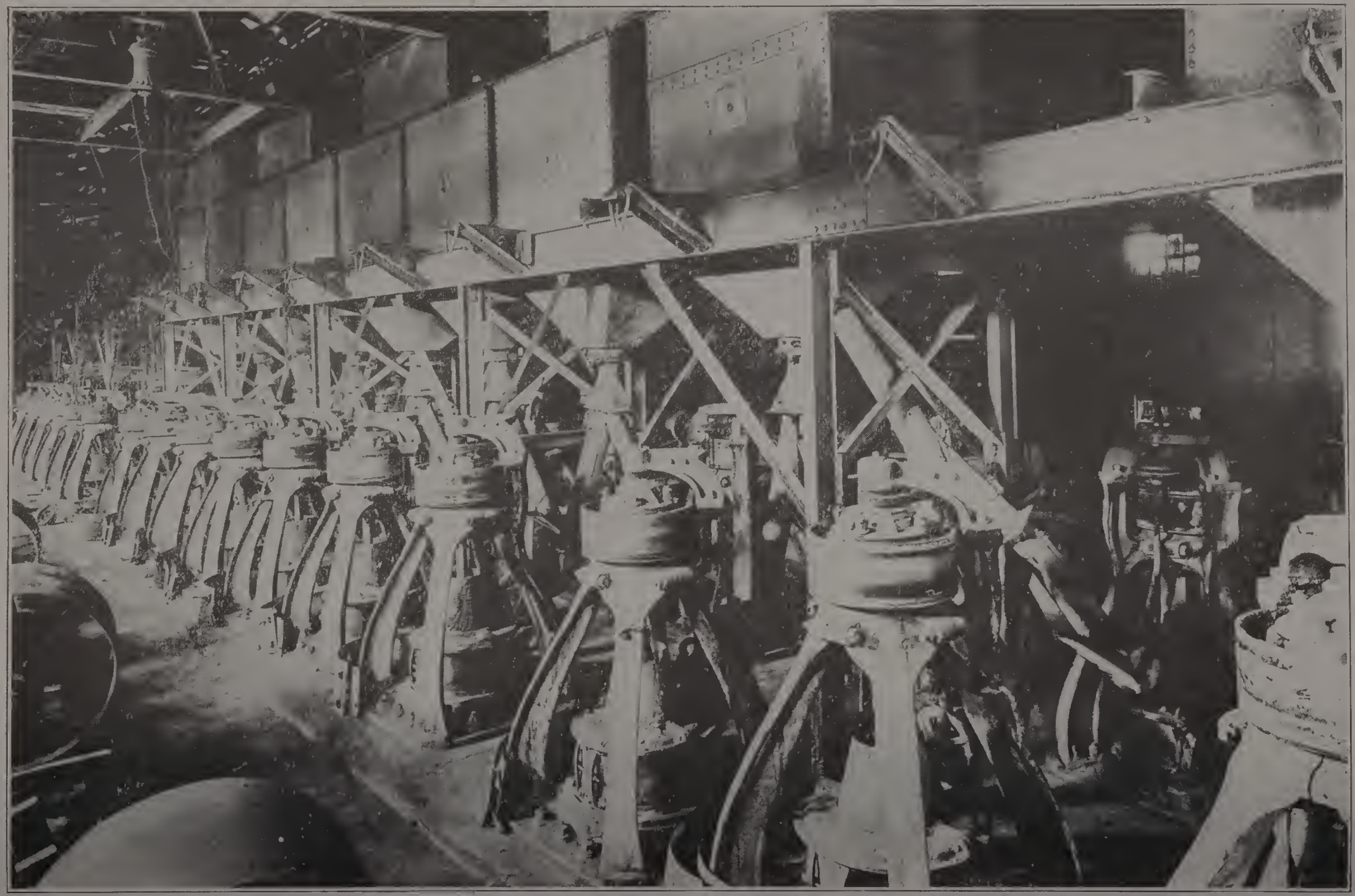
A

B

SAND SCREENED FROM NATURAL GRAVEL OF GLACIAL ORIGIN.

Reproduced at actual size.

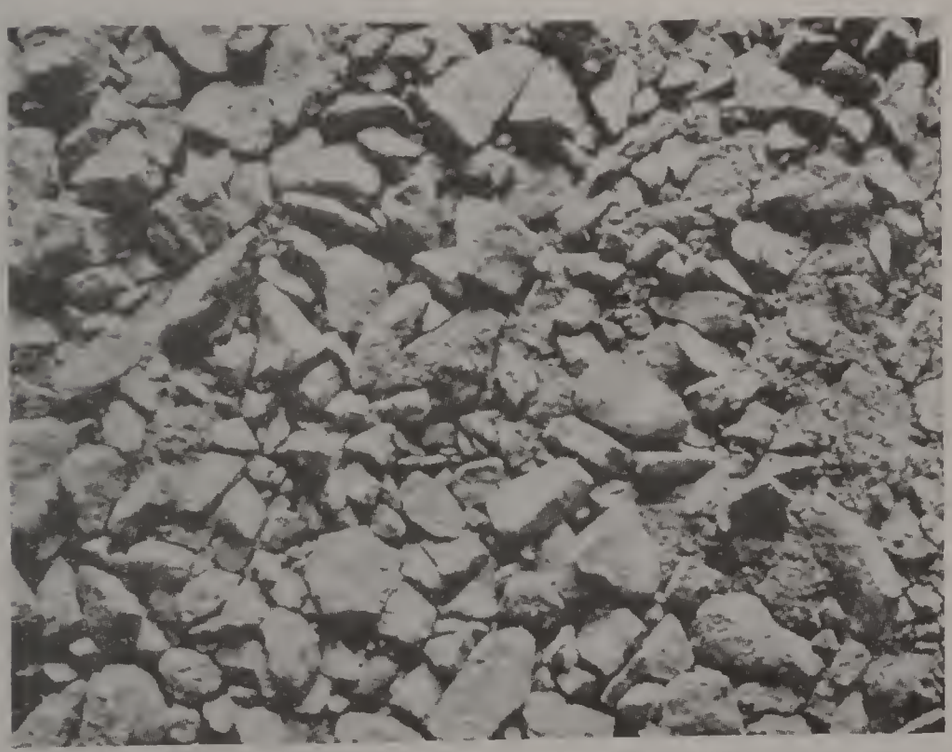
Plate 1—Materials and Manufacture of Concrete.



BATTERY OF GRIFFIN MILLS GRINDING CEMENT CLINKER TO PORTLAND CEMENT.

In some plants, grinders of this type are used instead of tube mills for the final grinding.

A
LIMESTONE SCREENINGS FROM CRUSHER.



B
LIMESTONE SCREENINGS SEPARATED FROM CRUSHER-RUN MATERIAL BY ¼-INCH SCREEN.

INTERIOR OF PHYSICAL LABORATORY IN A PORTLAND CEMENT PLANT.
Here tests are regularly made for strength, soundness, etc.

gravel. Six barrels of gravel, three of sand, and one of cement, for example, will not give ten (1+3+6) barrels of concrete, but will give only a little more than six barrels.

The volume or yield of the concrete affords, in fact, one method of determining the best proportions of aggregates. If the proportion of cement is kept the same, that mixture of coarse and fine aggregates will be the best which will give the smallest volume of concrete from a certain weight of aggregate. This test is called the **yield** or **volumetric test,** and gives a rough but very quick and convenient indication of the relative density and strength of the concrete resulting from different mixtures of aggregates. The smaller the volume, the greater density and strength, and the better the quality of the concrete.

There is the closest relation between the density and the strength of concrete. Even a slight increase in weight per cubic foot will add very decidedly to the strength. In this connection the importance of the coarser aggregates cannot be too strongly insisted upon. The use of coarse material is essential to density, since coarse material contains the smallest amount of voids. Different kinds of sand, gravel, and stone vary greatly in the extent of their voids; and by judiciously mixing coarse and fine materials, the voids may be much reduced, and the weight and density of the concrete increased. The following figures illustrate how voids may be reduced

and weight increased by mixing fine and coarse materials:

	Per Cent Voids	Weight per Cubic Foot
Pebbles, about 1 inch	38.7	101.2 lbs.
Sand, 30 to 40 mesh	35.9	105.8 "
Pebbles mixed with sand, the sand being 38.7 per cent of the volume of the pebbles, or just enough to fill the voids.	19.2	133.5 "

If sand be screened so as to take out the coarse grains, the voids will be increased and the weight reduced, thus injuring the sand for making concrete. Strength may be improved by adding coarse material, even though the proportion of cement is thereby reduced. This has been repeatedly shown by experiment. A mixture of cement and sand alone will form a rather weak concrete, especially if the sand is fine. By adding gravel—say about twice the quantity of gravel that there is of sand, or a little more—a concrete will be obtained containing, of course, a greatly reduced percentage of cement, but of greatly increased strength.

In selecting aggregates for concrete, then, it may be laid down as a general rule that those should be chosen which give the greatest density. If it is practicable to mix two materials, as sand and gravel, the proportion which gives the greatest density should be determined by experiment, and rigidly adhered to, whatever may be the proportion of cement it is decided to use. Well-proportioned dry sand and gravel, or sand and

broken stone, well shaken down, should weigh at least 125 lbs. per cubic foot. Limestone screenings, owing to minute pores in the stone itself, are somewhat lighter, though they may give equally strong concrete. They should weigh at least 120 lbs. per cubic foot. If the weight is less, there is probably too much fine dust in the mixture.

Selection of Sand. For a rich mortar—that is, one relatively rich in cement—a coarse sand is best. For a lean mortar, a small admixture of fine sand with the coarse is beneficial. If very fine sand is the only kind available, the mixture must be excessively rich in cement, and a smaller quantity of the sand in proportion to the gravel or stone may be used. To secure great density and practical water-tightness of concrete, a larger percentage of fine grains is needed than is theoretically necessary for maximum strength. If a good, coarse sand is not available, almost any size of sand may be employed, provided a sufficient proportion of cement is used; though in this case, tests should be made to see that the mortar or concrete sets and hardens properly. There is one exception, however, to this rule—namely, in the case of concrete to be laid in sea water, where fine sand must never be used.

To choose between two sands, make each into a mortar with cement in the required proportions; and the sand producing a smooth mortar having the smallest volume will give the greatest strength.

Coarseness and **cleanness** are the two most important characteristics of sand. **Sharpness**—ascertained by examination under a magnifying glass, or, more simply, by the gritty "feel" of the sand when rubbed between the fingers—is sometimes specified as a necessary requirement, but is rather an indication of cleanness and purity, showing no excess of fine material, than an absolute essential of strength; for, of two sands having grains of the same size and containing the same amount of dust or fine material, that having the rounded grains will give the denser and stronger mixture.

A sand which soils the hands when rubbed between them, or which has little of the gritty feeling, should not be used. Another method of determining whether the sand is clean is to drop a quantity into a pail of clear water. If the water in two minutes is clear enough to enable you to see the sand at the bottom, the sand is clean. Still another method is to put some of the sand into a fruit jar with some water, shake well, and let the jar stand till all the materials have settled. If a layer of mud is seen over the sand, the sand is not clean, and should not be used. A small percentage of dirt, such as fine clay or other mineral matter, is not necessarily harmful; and for lean mortar, the presence of such impurities—up to, say, 10 per cent—may be actually beneficial. For rich mixtures, on the other hand, an excess of dirt or fine material

spells weakness, and setting may be seriously delayed.

The presence of any considerable proportion of **mica** will destroy the value of any sand for concreting purposes. Its effect is more injurious upon fine sands than upon coarse. It greatly increases the amount of voids, and the smooth surfaces of the mica particles do not permit of a good bond with the surrounding cement.

In a great many sections of the country, the sands contain so much mica as to be almost worthless. The coarser sands seldom contain over 3 or 4 per cent; but some of the finer sands, which, at best, will not make a concrete more than one-third as strong as the coarser, contain 10 to 12 per cent of mica. Tests show that as mica increases, voids increase, weight diminishes, and there is loss of strength at any age of the mixture. A sand containing as high as 20 per cent of mica, will have 67 per cent of voids, will require three times the amount of water for mixing that sand without mica would require, and will show a decrease of 20 per cent in weight, and a loss of two-thirds in the strength of the mixture.

The **weight of sand** is to some extent an indication of its quality. A heavy sand is generally denser, and therefore better, than a light sand, as it ordinarily indicates coarseness and good grading of particles, with correspondingly low percentage of voids. This, however, is a very

unsafe guide to follow, on account of the fact that the presence of moisture may cause as much as 20 per cent variation in weight, and fine sands require more water than coarse.

Tests made by Mr. Sanford E. Thompson on a certain natural sand, showed 38 per cent of voids in the sand when dry, and 52 per cent in the same sand when moist. The dry sand averaged 103 pounds to the cubic foot; but after being wet by rain, allowed to drain for two days, and then shoveled into a measure and weighed in exactly the same way, it averaged only 83 pounds. This author therefore lays but little stress on the determination of voids in the sand, preferring to make the determination after the sand has been mixed with cement. That sand which, with the same percentage of cement, shows the lowest total proportion of voids, both of air and of water, and consequently gives the heaviest and densest mixture, is the best.

No absolute statement can be made as to the value of sand as compared with **crushed stone screenings.** Here also, aside from the quality of the stone itself, a proper grading of coarse and fine particles is of prime importance. In some cases, the strength of the mixture is greatly added to, because of the screenings themselves having a certain degree of hydraulic activity.

Natural sand or screenings usually contain sufficient fine material for rich mortars, such as 1 : 1, 1 : 2, or 1 : 2½ (that is, where the sand or screenings do not exceed two and a-half times

the volume of cement); but for leaner mixtures, such as 1 : 3, 1 : 4, or 1 : 5, an addition of fine particles is of advantage by assisting the cement to fill the voids.

It is better to err on the side of coarseness than of fineness, for, other things being equal, a coarse sand will give a denser and stronger concrete or mortar; but a judicious proportioning of the fine and the coarse will insure the best results all around; and, in the case of watertight work, it seems to be the preferred practice to make a slight sacrifice of the theoretical requirements of strength, by increasing the proportion of fine material—except, as already noted, in the case of concrete to be deposited under sea water.

The importance of a careful grading of different-sized aggregates as affecting the strength of concrete, is graphically illustrated in the samples of natural bank sand and gravel and limestone screenings shown respectively in Plates 1 and 2. The samples are photographed and reproduced at actual size.

In Plate 1, both samples (**A** and **B**) were taken from the same natural bank of sand and gravel of glacial origin, at Attica, Indiana. They differ only in the size of the grains, due to screening; and give, in a general way, a fairly correct idea of the appearance of a well-graded sand. **A**, the finer sample, contained 34 per cent of voids; **B**, the coarser, 26.9 per cent. When made up into a 1 : 3 mortar—that is, 1 part

cement to 3 parts aggregate—the mortar from the coarser material, in one year, developed a compressive strength of 7,750 lbs. per square inch, whereas the finer material gave a mortar having a compressive strength of only 4,475 lbs. per square inch—a difference in strength of over 70 per cent in favor of the coarser material.

A similar relative superiority of coarse as compared with fine material, is shown by the samples of limestone screenings illustrated in Plate 2. Sample **A** was taken from a crushing plant near St. Louis, Mo., and shows a screening in which the grading is not at all uniform. Sample **B** came from a plant at Greenfield, Ohio, and represents the screenings separated from the crusher-run material by a ¼-inch screen; and it will be noted that, with the exception of the large proportion of fine material, the screenings are very well graded. Sample **A** contained 42.1 per cent of voids; **B**, 37.5 per cent. **B** gave a 1 : 3 mortar having a compressive strength, at one year, of 8,500 lbs. to the square inch, as compared with only 4,908 lbs. per square inch for **A**. Here, again, the difference in strength was over 70 per cent in favor of the coarser screenings, showing that a large proportion of fine particles is detrimental to strength.

The relative percentage of voids in two materials, one of uniform size and shape, and the other of irregular size and shape, is clearly shown by comparing the gravel of Sample **B**, Plate 1, with a mass of round shot of uniform

size. In the irregular gravel, the voids equal 26.9 per cent, while in the shot they equal 47.6 per cent. That is to say, there will be nearly twice the space in gravel to fill with cement if the particles are round and all the same size.

Testing Sand. Tests made by M. René Feret, a French engineer, with mortar made from different natural sands, showed great variation in strength, due merely to the different degrees of fineness in the various sands. He used a mixture of 1 : 2½ by weight—that is, 1 part Portland cement to 2½ parts sand. At the age of five months, the mortars made from the various sands showed varying degrees of tensile strength, in every case favoring the coarser material; and in compressive strength, the differences were even more marked. The results are shown in Table III.

TABLE III

Effects of Fineness of Sand on Strength of Portland Cement Mortar

Age of Mortar, Five Months

Mortar Made from	Tensile Strength	Compressive Strength
Coarse Sand	421 lbs. per sq. in.	5,200 lbs. per sq. in.
Medium "	368 " " " "	3,400 " " " "
Fine "	302 " " " "	1,900 " " " "

Similar tests were conducted by Sanford E. Thompson in 1905, on Portland cement concrete. The aggregates were all of the same kind of material, varying merely in the sizes of the particles; and the proportion of the cement to the total aggregate by weight remained the same. The results showed a strength of the con-

crete in some cases two and a-half times what it was in others.

Yield or Volumetric Test for Sand. Reference has already been made in a general way to what is known as the "yield" or "volumetric" test, the purpose of which is to determine what one of two or more sands will produce the denser, and therefore the stronger, mortar in any given proportions. In a paper read before the National Association of Cement Users (June, 1906), Mr. Thompson described in detail the method of making this test, in substance as follows:

If the proportions of the cement to sand are by volume, they must be reduced to weight proportions; for example, if a sand weighs 83 pounds per cubic foot moist, and the moisture found by drying a small sample of it at 212 degrees F. (the temperature at which water boils and is driven off as steam) is 4 per cent, which corresponds to about 3 pounds in the cubic foot, the weight of the dry sand in the cubic foot will be 83–3=80 pounds. If the proportions by volume are 1:3—that is, one cubic foot of dry cement to three cubic feet of moist sand—and if we assume the weight of the cement as 100 pounds per cubic foot, the proportions by weight will be 100 pounds of cement to 3 times 80, which is 240 pounds of sand; and this corresponds to 1:2.4 by weight.

A convenient measure for the mortar is a glass graduate, about one and one-half inches in diameter, graduated to 250 cubic centimeters. A convenient weight of cement plus sand for a test is 350 grams. The sand is dried and mixed with cement in the calculated proportions, in a shallow pan about ten inches in diameter and one inch deep. The mixing is done conveniently with a 4-inch pointing trowel. The dry, mixed material is

formed into a circle as in mixing cement for briquettes, and sufficient water added to make mortar of plastic consistency, similar to that used in laying brick masonry. After mixing about five minutes, the mortar is introduced, about 20 cubic centimeters at a time, into the graduate; and, to expel any air bubbles, it is lightly tamped with a stick having a blunt end. The mortar is allowed to settle in the graduate for one or two hours, until the level becomes constant, when the surplus water is poured off, and the volume of the mortar in cubic centimeters is read.

The other sands that are to be compared with this are then prepared in the same way. After testing all the mortars, the sand which produces the strongest mortar is immediately located as that in the mortar of lowest volume. In other words, **the best sand is that which produces the smallest volume of mortar with the given proportions by weight.** If the sands that are being compared differ appreciably in specific gravity, allowance for this, of course, must be made in weighing them out to be tested, so that the sum of the volumes of the sand particles will be the same in each case. In general, however, the sand which, in any given proportion, produces a mixture of smallest volume, will also produce a mortar of greatest strength.

In a number of tests made with the same proportions of cement and sand by weight, the mortar of medium sand was found to occupy a volume 7½ per cent in excess of coarse sand mortar; while fine sand mortar exceeded coarse sand mortar by 17 per cent in volume—the results here again favoring the coarser material.

By similar systematic trials, the best mixture of two or more sands, or of various sands with various other aggregates, for making concrete, may also be found. Larger quantities of

materials must be used than in testing sand for mortar as above described; and, instead of a glass graduate—which would be too weak to stand the necessary light ramming—a short length of cast-iron pipe, closed at one end, may be used. Those aggregates which, mixed with cement in the required proportions, produce the smallest volume of concrete, are ordinarily the best, though, in this case, the shape of the particles and the hardness of the coarser aggregates must also be considered, as explained below.

Standard Sand. As a standard sand for testing purposes, the Committee on Uniform Tests of Cement, of the American Society of Civil Engineers, recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch, and retained on a sieve having 30 meshes per linear inch. The committee says that sand having passed the No. 20 sieve shall be considered standard when not more than one per cent passes a No. 30 sieve after one minute of continuous sifting of a 500-gram sample.

Selection of Stone and Gravel. So wide a variation in texture and strength is found in stones, even of the same class, that no hard and fast rule can be laid down as to their comparative values for concrete. The actual, intrinsic strength of the stone itself is an all-important factor, the hardest stone—other things being equal—producing the strongest concrete.

In order of their value for concreting purposes, different stones may be listed approximately as follows: (1) **Trap**; (2) **Granite**; (3) **Gravel**; (4) **Marble**; (5) **Limestone**; (6) **Slag**; (7) **Sandstone**; (8) **Slate**; (9) **Shale**; (10) **Cinders**. Sandstone is ordinarily not worth more than three-fourths the value of trap, and the value of slate is less than half that of trap.

The difficulty of making anything like a final, general comparison is further increased by the fact that the relative value of specimens of any one kind of stone is affected by the proportions used, and will also vary with the age of the concrete. Gravel concrete, for example, because of the rounded surfaces, may, at the age of one month, be weaker than concrete made from comparatively soft broken stone; but at the end of one year may far surpass the latter in strength. Gravel makes a dense mixture, and, if much cheaper than crushed stone, may ordinarily be substituted for it.

Where stone is used as aggregate, the relative size of the particles affects the quality of the concrete, just as in the case of sand; but the strength and density of the concrete depend also on the **hardness** of the stone itself, on the **shape** of the particles, and on their being kept within certain limits as to **maximum size**.

Porous stones, like sandstone, should be avoided if possible. They are inherently weak, and, unless thoroughly soaked before mixing, will give trouble by absorbing excessive amounts

of water, thus preventing plasticity and a thorough mixture. The best crushed stone is that which is hard; with angular fragments, preferably of cubical shape and ranging up to the maximum size that can be handled in the work; with all particles smaller than, say, one-fourth inch screened out to be used as sand; and with the sizes of the remaining coarse stone varying from small to large, the coarsest predominating. A flat-grained material packs less closely than, and is always inferior to, stone of angular or cubical fracture.

Gravel should also meet these same requirements, except as to angular shape, its particles being usually rounded by erosion. It must, in addition, be clean, because clay or loam adhering to the particles weakens or destroys the adhesive power of the cement. Tests made by the Boston Transit Commission showed a tensile strength of 605 lbs. per square inch for concrete made with clean gravel, as against 446 lbs. when made with dirty gravel.

If a gravel and a crushed stone are of equal hardness, the stone, on account of its angularity, will probably give a better binding quality to concrete than will the gravel, which is smooth and rounded. Gravel, however, is used quite as extensively as crushed stone, and with good results; and it has frequently the advantage of greater cheapness and greater accessibility of supply.

Even in the same bank of gravel or the same

pile of crushed stone, the proportions of fine and coarse material will vary at different points. As a result, the only way to secure absolute uniformity in the concrete, is to separate the fine material from the coarse by **screening**, and then remix in the proportions required by the specifications. This adds to the cost, but insures the best results.

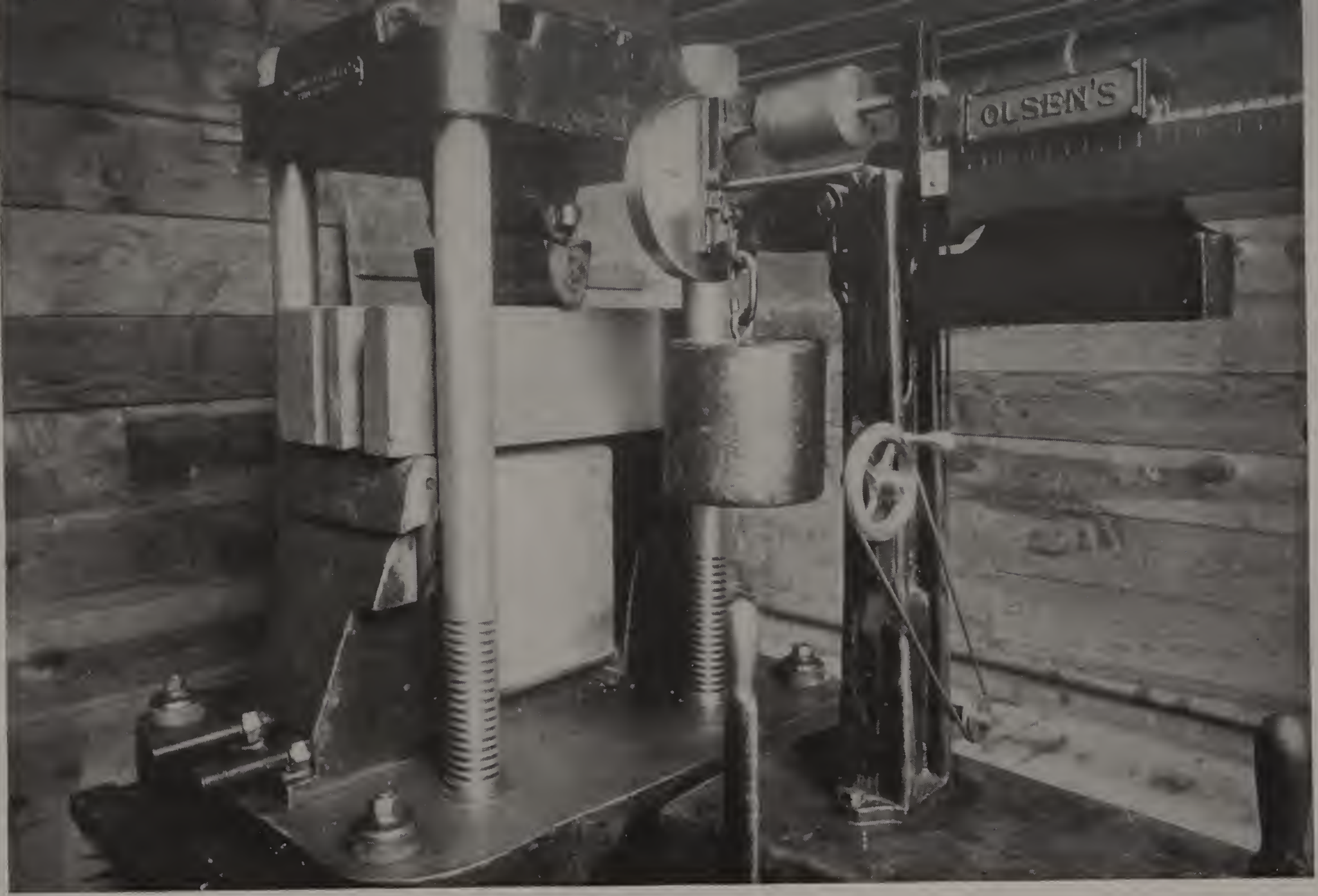
Sizes to Use. In the case of both stone and gravel, the coarse material should predominate, and, as already noted, the size of the coarsest particles of stone should be as large as can be handled in the work. Not only is the strength of the concrete increased thereby, but the use of leaner and cheaper mixtures is rendered feasible with equally good results. In **mass concrete**, however, the stones, if too large, are liable to separate from the mortar unless placed by hand or derrick as in rubble concrete, and a practical maximum size is 2½ or 3 inches. In **thin walls, floors, columns, tanks, conduits, and other reinforced constructions**, a 1-inch maximum size is generally as large as can be easily worked between the steel, though sometimes 1½-inch is used. In some cases where the walls are very thin—say 3 or 4 inches—a ¾-inch maximum size is more convenient to handle.

Rubble Stone and Its Use. Sometimes a saving of expense may be secured in the construction of massive work such as walls, piers, abutments, dams, breakwaters, etc., by the introduction of large stones into the mass. When this

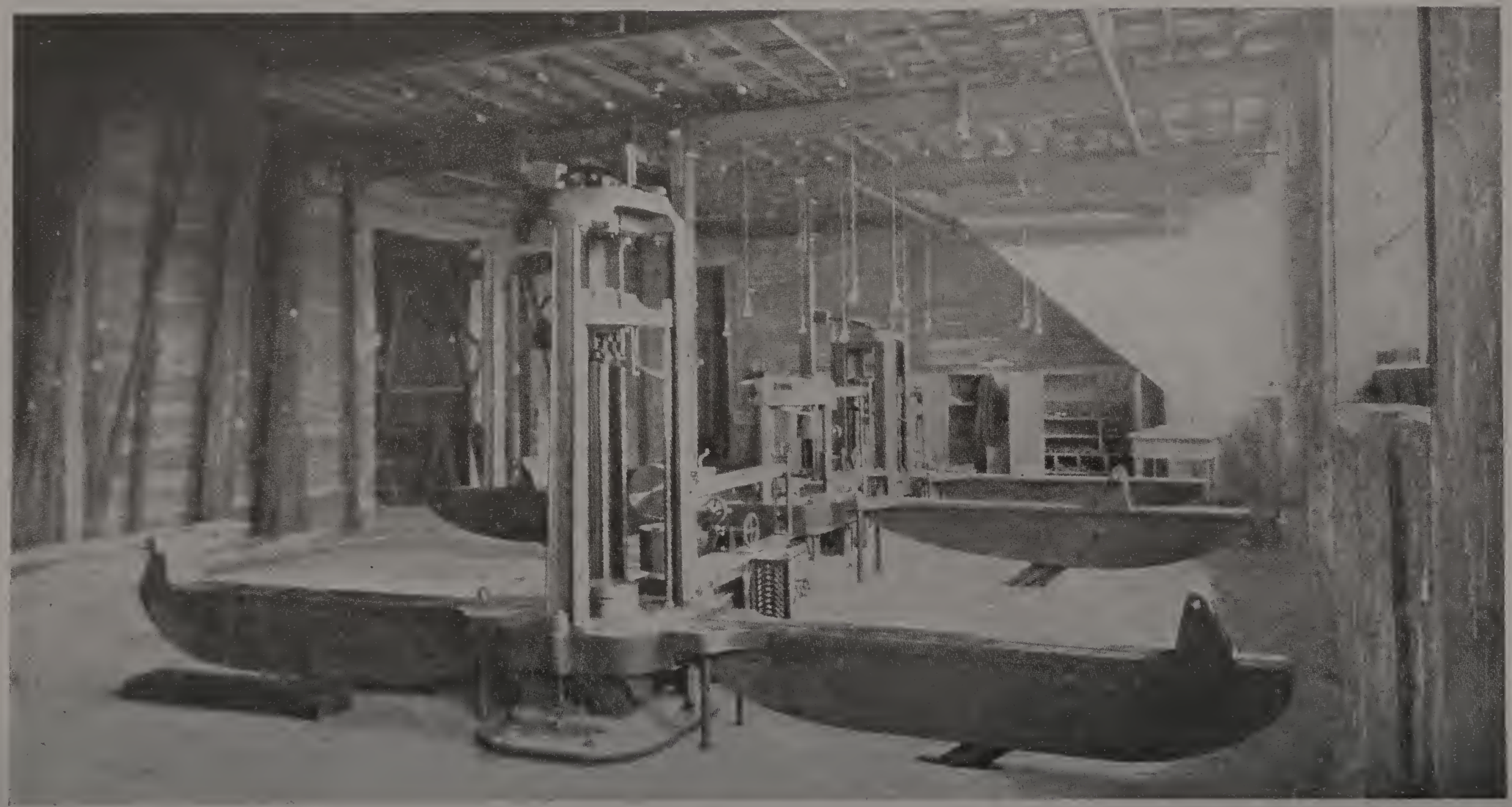
is done, the stones should be used only in the middle or center of the wall, and each one should be so placed that there will be ample room between it and its neighbor. Thorough tamping about the stone is necessary to insure the cement adhering to its surface, and also to insure a perfect filling of the voids. Stones used in this way are better if their surface is irregular than if they are smooth or rounded, as the voids of the irregular stone afford better holding power for the cement.

These large, irregular pieces of stone are called **rubble,** and the concrete made by using them is known as **rubble concrete.** The saving of expense in using this form of concrete is due to the fact that not only is the expense of crushing the stone done away with, but also there is less cement required than with finer aggregate, since a large percentage of the space is filled with solid stone.

In some classes of work, great weight in concrete is desirable—as, for example, in breakwaters, dams, etc., where there will be great shock or pressure; and to such cases rubble concrete is very well adapted, as it is much heavier per cubic foot or cubic yard than ordinary concrete. Compared with rubble masonry, it will usually be cheaper than the latter. This will always be the case if the rubble concrete can be placed without the construction of forms; but in the case of walls of medium thickness, say



TESTING CONCRETE BLOCKS WITH LOADS APPLIED AT CENTER.
Blocks are later tested for crushing strength. Government laboratories at St. Louis, Mo.



INTERIOR VIEW OF BEAM TESTING ROOM, LABORATORIES FOR TESTING STRUCTURAL MATERIALS, U. S. GEOLOGICAL SURVEY, ST. LOUIS, MO.

ROOM FOR STORAGE OF TEST PIECES, LABORATORIES FOR TESTING STRUCTURAL MATERIALS, U. S. GEOLOGICAL SURVEY, ST. LOUIS, MO.

OLDEST HOUSE IN THE UNITED STATES—ADOBE CONSTRUCTION, AT SANTA FE, NEW MEXICO.

3 to 4 feet, the saving in the concreting material will ordinarily be more than offset by the cost of the forms.

In proportioning rubble for concrete, the amount of stone is fixed at a certain percentage of the space to be filled. This percentage will vary with the size of the stone that is used, being larger with the larger sizes of stone, and smaller with the smaller sizes. In other words, a greater percentage of a given volume will be filled if the stone is large size than if it is small size. If the rubble is of such size that it can be handled regularly by one man or two men, about 20 to 25 per cent of the space filled by the concrete will consist of the stone, leaving 80 to 75 per cent to be filled with mixed concrete. In the case of stones that can be handled only by a derrick, the percentage may run from about 33 per cent for the smaller sizes to from 55 to 65 per cent for large-size stones averaging 1 to 2 cubic yards each or larger, the amount of mixed concrete necessary thus ranging from 66 to 35 per cent or less, according as the stone is increased in size.

The stones should be completely enveloped in the concrete, and the outermost pieces should be buried at least 5 to 12 inches beneath the surface. A very wet mixture is generally used in placing rubble concrete; and in this case the stones may be placed much closer together than when a medium or dry mixture is used. If the concrete is not mushy enough to flow into

and fill all the spaces, it must be thoroughly tamped to insure that none of the crevices are left empty.

Fireproof Aggregates. Aggregates differ greatly in the resistance they offer to high temperatures. But even an aggregate naturally weak in this respect—such as limestone—will give a concrete available for fireproof construction, if, in depositing the concrete, the precaution is taken to insure the burial of the coarser aggregate behind a facing very rich in cement.

Slag and pure quartz sand are two of the best fireproof aggregates. The former is itself a product of enormously high temperatures. Its angularity, density, and cheapness are all in its favor. In the selection of slag, however, care should be taken to avoid any that contains sulphur, since that chemical is detrimental to Portland cement.

Other substances that are considered fireproof are **firebrick, broken pottery, hard clinkers, cinders,** and **pumice-stone** or **lava,** all of which have been through the fire. If cinders are used, they should be thoroughly screened through a mason's screen, to remove the dust.

Limestone, granite, and flint crack and even decompose under the action of great heat. Concrete made from "coke breeze," as the refuse from coke furnaces is called, will gradually crack and crumble when subjected to high temperatures.

WATER FOR CONCRETE

Water has two functions to perform in concrete work. Its presence is necessary to develop the hydraulic activity of the cement. Aside from this, the part it plays in concrete is merely that of rendering the mass plastic and insuring a thorough mixture. It does not seem to have any direct bearing on the adhesive power of cement; but it indirectly affects the strength of concrete through its action in rendering possible a more thorough compacting of ingredients, and consequently increasing the density of the resulting mass of concrete.

In all ordinary concrete work, the general rule may be laid down, that **water should be liberally used.** This greatly improves the density and strength of concrete. Except in special cases—as, for example, in making concrete blocks or casts, where the product has almost immediately to be self-supporting—enough water must be used to make the concrete thoroughly soft and plastic, so as to quake strongly when rammed. If mixed too dry, the concrete will never harden properly, and will be light, porous, and crumbling. In some work—as, for example, in placing concrete around reinforcing steel members—the best results can be secured only by an excessively wet mixture, mushy, and soft enough to run off the shovel.

Water that is to be used for concrete should,

above all things, be **clean.** Dirty water will have the same effect as dirty sand or dirty gravel, weakening the concrete and in some cases retarding the setting.

Fresh cement requires more water than cement which is stale. In cold weather, the water may be warmed; but in such cases, there arises the danger of having bubbles of air or of water vapor scattered through the interior of the concrete, leaving small holes in the mass that weaken it.

Water should also be **free from acids or strong alkalis.** Cement is chemically basic, and is therefore naturally active to a greater or less extent with the various acids. If concrete is to be exposed to attack from acid-laden fluids, a reliable waterproofing process should be adopted.

The action of **sea water** on Portland cement concrete has exercised the minds of engineers for many years. The tendency to disintegration that has been noticed is purely the result of chemical action and the formation of soluble salts. It is checked by the use of cements relatively low in lime, alumina, and sulphates, and by the adoption of a waterproofing process which will prevent the diffusion through the concrete of the active constituents of the sea water.

Alkalis in water may hasten the setting and hardening of concrete, but are ultimately detrimental to strength. In a certain soap factory, on one occasion, water containing lye was used in

laying several hundred feet of concrete flooring. It was discovered that the lye water made a harder concrete in much less time than would have been the case with pure water. The floor wore well for two years, but then began to crumble, and rapidly disintegrated. The daily sweepings consisted largely of concrete, and in a short time the four-inch floor of concrete was entirely swept away in spots.

PROPORTIONING OF CONCRETE INGREDIENTS

The importance of a careful grading of coarse and fine ingredients has already been emphasized, and the general principles laid down which should govern the selection of aggregates for any proposed work.

It is equally essential, for the sake of economy and efficiency, that the concrete worker shall understand how to determine exactly the relative proportions of cement, sand, and coarser aggregates which must be used to obtain the densest and strongest concrete.

At the outset, it should be noted that in practical construction work, proportions are always indicated **by measured volume, not by weight.** In laboratory tests, where extreme accuracy of graduation and measurement is necessary, and also in the exact proportioning that is needed in the manufacture of Portland cement to secure absolute uniformity in the product, the measur-

ing of ingredients is done by weighing them; but in the work of ordinary concrete construction, measuring by volume is much the easier and more convenient method, and gives an accuracy

Fig. 1. Relative Volumes of the Solid Ingredients in a 1:2:4 Mixture, and of the Resulting Mass of Concrete.

sufficient for all practical purposes. Thus a concrete designated 1:2:4 does not mean one containing 1 lb. cement to 2 lbs. sand to 4 lbs. of coarser aggregate; but it means a mixture consisting of 1 part or measured volume of cement, twice as much sand, and four times as much of the coarser aggregate (stone or gravel), making the whole mixture contain seven parts, though, when mixed together, these seven parts will not occupy seven times the volume of one part, but only a little more than the volume of the four parts. Fig. 1 illustrates graphically the relative volumes of the ingredients in a 1:2:4 mixture, and of the resulting mass of concrete.

In general practice, there is wide variation in regard to the actual proportions used in the mixing of concrete. In many cases these proportions are decided upon in so crude a manner, and the measuring is also done so roughly and careless-

ly, that material is wasted, the cost of work unnecessarily increased, and the results indifferent or unreliable.

The only way to determine the **exact** proportions of cement and aggregates required for perfect concrete, is to make an **experimental test** in each case. Fortunately this is a comparatively easy thing to do; and, for the practical concrete worker, it will ordinarily consist merely in determining the **percentage of voids** contained in the sand and other aggregates—that is, the proportion of space that has to be filled with fine material.

As a result of the number of such special tests which have been made by engineers, and the careful investigations that have been carried out in connection with actual examples of construction, an immense fund of valuable practical information has been accumulated, covering every detail of concrete work. This information has been embodied in the form of **working rules** and **labor-saving tables** which render it immediately available for practical application. By merely referring to these tables and observing these rules, the concrete worker can determine with a degree of accuracy sufficient for all practical purposes the proportions of cement and aggregates to be used in any kind of concrete work, and can be sure that he is adopting the proper methods of procedure.

No table, however, can be compiled, from which at least some slight variation is not allow-

able. This is because voids and weights of even the same kinds of aggregates vary so greatly, and the quantities of cement in original packages shipped by different manufacturers also differ considerably. The working tables, nevertheless, will indicate approximately the ideal proportions to use.

Determination of Voids

Since the object, in mixing materials of different sizes in concrete, is to fill all the spaces, it follows that the voids in the coarse aggregate will indicate the amount of sand to use, and the voids in the sand will indicate, though but roughly, the amount of cement to use.

Voids are usually referred to as a certain **percentage of the whole volume.** A gravel, for example, with 35 per cent of voids, means that in a volume of the gravel occupying 100 cubic feet of space, 35 cubic feet consists of voids or empty spaces that have to be filled.

Having selected the available stone or gravel best adapted for the character of construction desired, any one of several different methods may be employed to determine the percentage of voids.

Voids in Coarse Aggregates. A very simple method of determining **voids in coarse aggregates,** described by Albert Moyer, is in substance as follows:

Make a box that will contain 3 cubic feet (say, 1 by 1½ by 2 feet, inside dimensions). Dry the aggregate by heating to 212 degrees F., the boiling point of water. If sand or screenings are present, they should be sifted out through a ¼-inch mesh sieve, to be used as sand. Throw stone in box loose, a small quantity at a time, and level off top with straight-edge. Having first weighed the empty box, weigh the box when filled; deduct the weight of the empty box from the gross weight, and divide the net weight (which is the weight of the contents) by 3, which will give the actual weight of one cubic foot. Then simply use Table IV, which shows at a glance the percentage of voids in coarse aggregates of varying weight per cubic foot.

TABLE IV

Percentage of Voids in Coarse Aggregates

Weight per Cubic Foot	Gravel	Sandstone	Limestone, Medium Soft	Limestone, Medium Hard; Sandstone, Hard	Granite; Blue Stone; Limestone, Hard	Granite, Hard; Trap, Medium	Trap, Hard
70 lbs.	57	53	55	57	58	60	61
75 "	54	50	52	54	55	57	59
80 "	51	47	49	51	52	54	56
85 "	48	43	45	48	50	51	53
90 "	45	40	42	45	47	48	50
95 "	42	37	39	41	44	46	47
100 "	39	33	36	38	41	43	45
105 "	36	30	33	35	38	40	42
110 "	33	26	29	32	35	37	39
115 "	30	23	26	29	32	34	36
120 "	27	20	23	26	29	31	34
125 "	24	16	20	23	26	28	31
130 "	20	13	17	20	23	26	28
135 "	17	10	13	17	20	23	25
140 "	14	6	10	14	17	20	23

A gravel, for example, which on being well shaken down weighs 110 lbs. per cubic foot, is shown by the table to contain 33 per cent of voids.

On account of the stone being measured loose, the voids shown in Table IV call for a little more of the fine material than is needed to just fill the actual voids in the concrete when tamped. They should, however, be used, as they make sufficient allowance to offset possible unevenness in mixing.

Another method of determining the voids in coarse aggregates, is given by S. B. Newberry, substantially as follows:

> Use a metal box of exactly one cubic foot capacity. Fill with the material to be tested; shake down well; strike off level; and weigh. Now pour water in, at one corner, until it rises even with the surface; and weigh again. The difference in the weights will be the weight of the water that was added to fill the voids. Now, since one cubic foot of water weighs 62.5 lbs., to find the percentage of the volume occupied by the water that just filled the voids, we divide the weight of the latter by 62.5 and multiply by 100.

Suppose, for example, that the box of dry aggregate weighs 92 lbs., and, when the water is poured in, it weighs 120 lbs. Then 120—92=28 lbs., the weight of the water. The amount of the voids will therefore be $(28 \div 62.5) \times 100 = 44.8$ per cent.

If the aggregate is dry and porous, it should be wetted before testing for voids, and then dried just enough to remove all moisture from the surface of the material. In this way the error that might occur through the absorption of water will be eliminated.

The object of pouring in the water at one point only, is to avoid entrapping bubbles of air.

Voids in gravel are seldom less than 30 per cent or more than 45 per cent. Broken stone, being angular, does not compact as readily as gravel, and hence has larger voids, though these will vary in amount, depending upon the character of the stone, whether it is broken by hand or in a crusher, and whether run of crusher is taken or the material has been screened.

Table V., compiled by M. Feret, shows the percentage of voids to be found in round pebbles and broken stone of different sizes, and also in mixtures of different sizes of each of these aggregates.

TABLE V

Voids in Pebbles and Broken Stone

Sizes of Aggregate				Voids (Per Cent) in	
Passing a ring of...	2.4 in.	1.6 in.	0.8 in.		
Held by a ring of...	1.6 "	0.8 "	0.4 "	Round Pebbles	Broken Stone
Parts Tested	1	0	0	40.0	53.4
" "	0	1	0	38.8	51.7
" "	0	0	1	41.7	52.1
Mixtures Tested.....	1	1	0	35.8	50.5
" "	1	0	1	35.6	47.1
" "	0	1	1	37.9	49.5
" "	1	1	1	35.5	47.8
" "	4	1	1	34.5	49.2
" "	1	4	1	36.6	49.4
" "	1	1	4	38.1	48.6
" "	8	0	2	34.1	.....

Voids in Sand or Screenings. To determine the percentage of voids in sand or screenings, Mr. Newberry's method as described above for coarse aggregates, may be used with slight modification. Instead of pouring the water into the sand-filled vessel, the sand should be poured into a vessel containing water. If the water be

poured on the sand, it will be impossible to get rid of all the air. The vessel should be filled not less than half-full of water, and the sand introduced slowly. As most sands have less than 50 per cent of voids, the water will overflow the vessel before it is level full of sand. Keep on putting in sand, however, until the vessel is level full, being careful at the same time to have the overflowing water carry off as little as possible of the finer sand. When the vessel is level full of the water-soaked sand, strike off smoothly over the top, and weigh. The calculation of voids is then made in exactly the same manner as for coarse aggregates.

Still another method of determining the voids in sand is to calculate it from the weight of a cubic foot and the **specific gravity** of quartz. The specific gravity of a substance is its relative weight compared with water as the unit. A substance having a specific gravity of 2.5, for example, will weigh 2.5 times as much as water, volume for volume. Now, sand is mostly broken quartz, and quartz has a specific gravity of 2.65. A cubic foot of water weighs 62.5 lbs. Therefore a cubic foot of quartz sand, if free from voids, would weigh $2.65 \times 62.5 = 165.625$ lbs. Now take a cubic foot of the sand to be tested, well shaken down, and weigh it. Suppose, for example, that it weighs 112 lbs. Subtract this from 165.625 lbs., the weight of a solid cubic foot of quartz, and we find a difference of $165.625 - 112 = 53.625$ lbs., which is the loss of weight due to the voids.

The percentage of voids will therefore be $(53.625 \div 165.625) \times 100 = 32.3$ per cent.

TABLE VI
Voids in Aggregates of Differently Shaped Particles

Aggregate	Voids	
	Unshaken	Shaken
Natural Sand (Rounded)	35.9 per cent	25.6 per cent
Crushed Quartzite (Angular)	42.1 " "	27.4 " "
Crushed Shells (Flat)	44.8 " "	31.8 " "
Residue of Quartzite (Flat)	47.5 " "	34.6 " "

The effects of various shapes of particles upon the percentage of voids in aggregates, is shown in Table VI. In the case of the shaken material, the shaking was carried on until no further settlement could be produced. It will be noticed that rounded particles have fewer voids than flat or angular.

Amount of Cement to Use

The amount of cement to be used in mixing concrete is generally stated as a certain **volume** or **measure**, in proportion to the number of volumes of the sand and the coarser aggregate, thus, 1:2:4 indicating a mixture in which there will have to be measured out twice as much sand as cement, and four times as much gravel or stone.

To determine the proper and most economical amount of cement to use in order to get a maximum density and strength of concrete, is therefore simply to determine whether we shall use a 1:2:4, or a 1:3.5:7, or some other mixture.

Fortunately, here again the problem confronting us need not present any very great difficulty. An absolute and exact determination would, indeed, be extremely difficult; but in all ordinary concrete work the ideal proportions can easily be approximated closely enough to prevent all unnecessary waste and to meet all practical demands.

The **working rules and tables** which have been compiled by engineers from the results of careful tests and wide observation of actual constructions, afford to all workers in concrete a ready guide to approved practice in the proportioning of mixtures. A number of these practical rules and tables will be given, sufficient to enable the reader to determine the proper mixture to use in any kind of concrete construction.

In the first place, the general principle may be laid down, that economy in the use of cement demands a careful **grading of the aggregates** so as to reduce voids as much as possible. If the coarse aggregate, for example, is very uniform in size, and its particles considerably smaller than the maximum allowed, the voids can be reduced by adding coarser material. If, on the other hand, the aggregate is already almost the full allowable size, the voids can be reduced by adding finer material ranging in size from the coarse aggregate to the coarsest sand. In all aggregates, in fact, the particles should range from fine to coarse, with the coarse predominating, as before explained. A cement and

Summer Cottage Built of Concrete on Shore of Lake Erie near Cleveland, Ohio.

Cellar walls and chimney of hollow blocks; first floor of reinforced concrete 3 inches thick, with pine flooring; house walls cement-plastered with pebble-dash finish; roof of concrete 1 inch thick spread over corrugated expanded metal (trussit) supported on iron rafters and waterproofed; porch floor of concrete on cinder foundation.

sand mixture will be vastly increased in strength by the addition of coarse aggregate. One barrel of cement, judiciously mixed with sand and gravel, may be as good as three barrels mixed with sand alone.

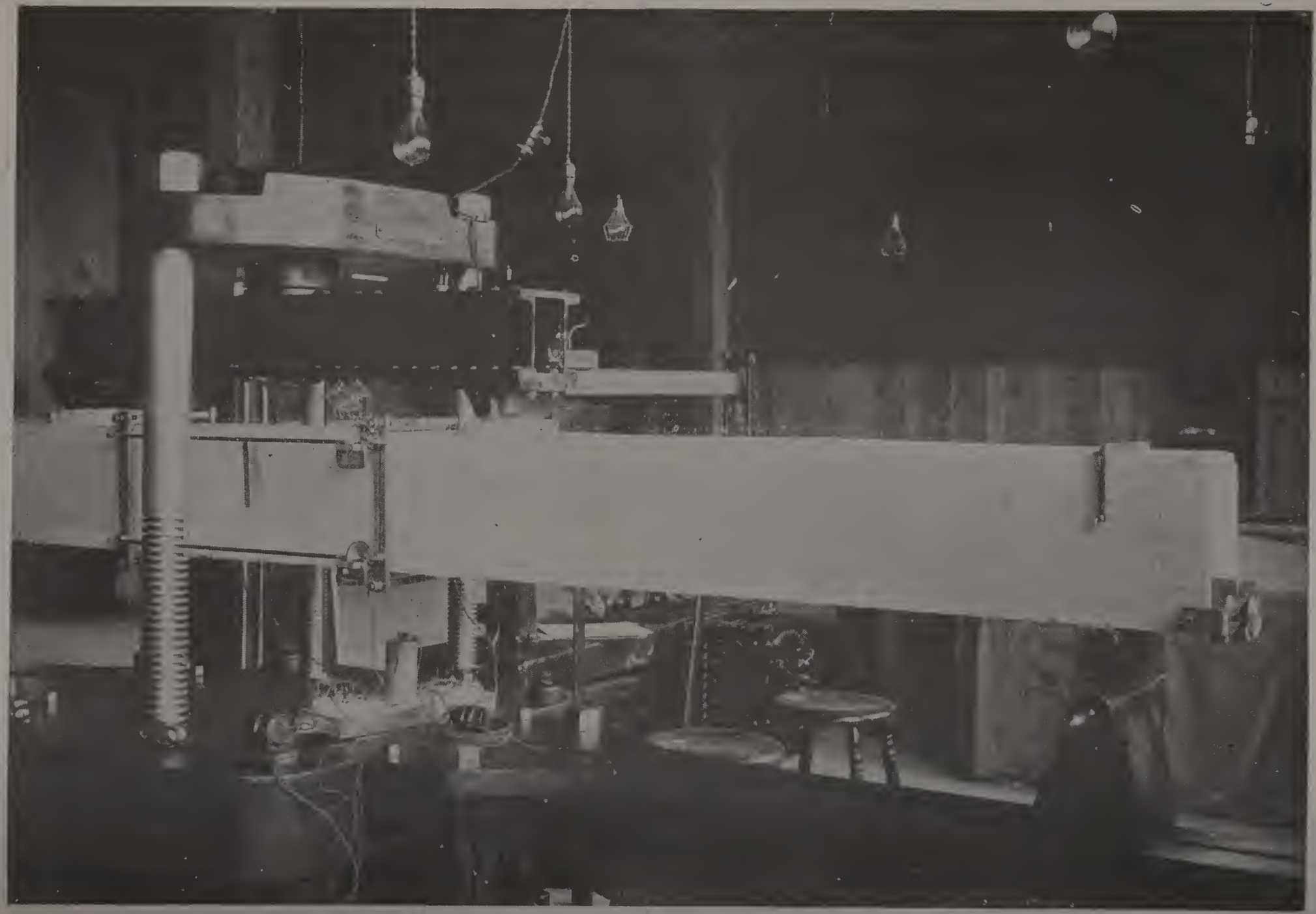
Having selected the sand and coarse aggregate available for the work, and calculated the percentage of voids, the proper mixture to use can be readily determined by reference to Table VII., compiled by Mr. C. W. Boynton, which shows the proportions of cement, sand, and stone to be used for various percentages of voids. This table, in order to be on the safe side and cover all the slight errors likely to occur in determining the voids, is based on an extra allowance of 10 per cent in the voids of the small aggregate.

TABLE VII

Proportions of Cement, Sand, and Stone for Different Percentages of Voids in Sand and Stone

Voids in Sand (Per Cent)	Parts of		Voids in Stone (Per Cent)															
	Cement	Sand	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
			Parts of Stone															
19	1	3.5	7.5	7.5	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.5	6.0	6.0	6.0	6.0	6.0
20	1	3.5	7.0	7.0	7.0	7.0	6.5	6.5	6.5	6.5	6.0	6.0	6.0	6.0	5.5	5.5	5.5
22	1	3.0	7.0	6.5	6.5	6.5	6.5	6.0	6.0	6.0	6.0	5.5	5.5	5.5	5.5	5.5	5.0
24	1	3.0	6.5	6.0	6.0	6.0	6.0	6.0	5.5	5.5	5.5	5.5	5.5	5.0	5.0	5.0	5.0
26	1	3.0	6.0	6.0	6.0	5.5	5.5	5.5	5.5	5.0	5.0	5.0	5.0	5.0	5.0	4.5	4.5
27	1	2.5	6.0	6.0	5.5	5.5	5.5	5.5	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5
28	1	2.5	5.5	5.5	5.5	5.5	5.5	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5
29	1	2.5	5.5	5.5	5.5	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.5
30	1	2.5	5.5	5.5	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0
31	1	2.5	5.5	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0
32	1	2.5	5.0	5.0	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0
33	1	2.5	5.0	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0
34	1	2.5	5.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
35	1	2.0	5.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5
36	1	2.0	4.5	4.5	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5
37	1	2.0	4.5	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5
38	1	2.0	4.5	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5
39	1	2.0	4.5	4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.5
40	1	2.0	4.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5
41	1	2.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
42	1	2.0	4.0	4.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.0	3.0

HOUSES A CENTURY OLD, BUILT OF NATURAL CEMENT CONCRETE BLOCKS.



TESTING A 13-FOOT CONCRETE BEAM.

View in U. S. Geological Survey laboratories at St. Louis, Mo., for testing structural materials. Load is applied at top of beam at points four feet from each end.

LANDSCAPE DOMINATED BY CEMENTED FEATURES.

Cement walks, cement-rubble bridge, walls, etc. In the background at right is an elaborate bridge.

WHERE JOSEPH ASPDIN, INVENTOR OF PORTLAND CEMENT, LIVED.

View at left is looking down Princess Street, Leeds, from the corner (at extreme left) near which Aspdin lived. His home stood at No. 3, the open door shown at right of righthand view. The old house was torn down about 1895, to make way for an extension of the "public house," or inn, on the corner—the "Three Horse Shoes"—which has had a continuous license since 1693.

By using this table, a great waste of cement may be prevented. Mr. Boynton cites an actual instance where, on a certain sidewalk job, a mixture of 1 part cement to 4 parts aggregate was being used. The aggregate was chiefly sand, only 2 per cent of it being gravel over ¼ inch, and none of it over ½ inch. The voids in the aggregate were about 30 per cent. Here the mixture was out of balance. Not only was there too much fine material, presenting a larger surface than the cement could cover, but the voids were larger than the cement could possibly fill. A reference to Table VII would have enabled the contractor to effect a saving of almost 40 per cent in the amount of cement used, and at the same time to deliver a far better job.

Where a sand contains 30 per cent voids, the table shows that only 2.5 parts of it should be mixed with 1 part of cement. And if coarser material is also available, say stone containing 45 per cent of voids, then 4½ parts of such aggregate should be added. The proper mixture would be 1:2.5:4.5; and if this mixture had been used on the job, the amount of cement necessary would have been only one-eighth the total volume, instead of the one-fifth called for by the 1:4 mixture—a saving of 37.5 per cent.

When a natural mixture of sand and gravel is available, the most reliable results will be obtained by screening it, and then remixing the fine and coarse material in the proper definite proportions. But if this cannot be done and un-

screened gravel has to be used, the proportion of cement can be roughly determined in the following manner: Take a portion of the gravel, and screen out the sand through a ¼-inch screen. If the volume of sand that passes the screen bears to that retained on the screen the ratio, of, say, 3 to 5, then the mixture to use is 1 part cement to 3+5=8 parts of the unscreened gravel, since this practically amounts to a mixture of 1 part cement, 3 parts sand, and 5 parts gravel.

The proportions for a mixture can also be calculated, though but roughly, from the voids in the sand and stone. Assume, for example, a sand with 33 per cent and a gravel with 40 per cent of voids. Then, to fill the voids in 100 volumes of gravel, we shall need 40 volumes of sand. To fill the voids in the sand with cement, we shall need 33 per cent of 40 volumes; but, allowing an extra 10 per cent for thorough coating of the particles and to avoid results of possible errors made in determining the voids, we shall take 43 per cent of 40 volumes, that is, 17.2 volumes of cement. The proportions of the mixture will then be 17.2 cement to 40 sand to 100 gravel, or, approximately, 1:2.3:5.8.

It is a common practice to increase the proportion of mortar more or less above that calculated, to compensate for imperfect mixing or to increase the strength of the concrete. In some cases a rich concrete may be necessary; in others

a poorer mixture will do equally well and be far more economical. This will depend on the character and location of the construction. However, proportions carefully determined according to methods such as those described above, are those which, with only slight variations, should be depended upon where very careful work and an economical use of cement combined with great density and strength are required.

Any great variation in the relative proportions of sand and gravel may convert a good, strong concrete into a weak and inferior one, even though the proportion of the cement be not changed. Strength may ordinarily be increased by adding to the proportion of cement, but a simultaneous increase of the sand would defeat the purpose in view, possibly weakening the concrete as much as the increase of cement would strengthen it.

It is a widely accepted conclusion among engineers, that a determination of the voids in sand affords at best only an approximate indication of the amount of cement that should be mixed with the sand in making mortar or concrete. Safety, it is true, may always be conserved, where this method is followed, by making due allowance for errors of calculation, imperfect mixing, etc.; yet this, they point out, may be at an unnecessary sacrifice of economy, and, for a determination of the ideal proportions, some other method is to be preferred.

That the voids in sand are an uncertain and

variable factor, is shown by several considerations. When water is added to sand and thoroughly mixed with it, the sand swells in volume, so that a cubic foot of the damp sand will weigh less, and will contain a far larger amount of voids, than a cubic foot of the same sand when dry. At the same time, the available voids in the damp sand are different from the available voids in the dry sand. Fine sand takes up more water than coarse, and increases considerably more in volume.

Moreover, the volume of any measured quantity of cement will be considerably reduced by the addition of water so as to work the cement into a thick paste. A cubic foot of packed cement does not signify a cubic foot of void-filling capacity when the cement is wetted and made into a thick paste.

In view of such considerations as these, many engineers prefer to base their proportioning of mixtures, so far as the cement and sand are concerned, not on the measured or computed volume of voids in the sand, but on the **density and plasticity** of the mortar produced by differently proportioned mixtures of cement and sand. The sample mixtures for examination (say five samples in proportions 1:2; 1:2.5; 1:3, etc.) are very carefully proportioned out by weighing, and are made to approximate as nearly as possible the conditions that will exist in actual work, as to compactness, amount of moisture absorbed, etc. The tests are taken in finely graduated measur-

ing tubes which show accurately the relation between the original volume of the sand and that of the resulting mixture, and also the slightest variations in volume of the mixture due to the different proportions. The density of the mortar increases with the amount of the cement, up to that point where a further increase of cement will cause an increase in the volume of the mortar. If the conditions of the work do not require a very dense or strong mortar, the proportions to be adopted will be indicated by one of the samples containing the least cement, but showing sufficient plasticity to insure a good bond in the concrete.

In principle this method of determining proportions is very similar to that depending on the "yield" or "volumetric test" for sand, which has already been described. Table VIII is a working table based on this method, compiled by Albert Moyer from the results of many tests. It shows the proportions of aggregates which will give maximum density with a minimum of cement. The voids in the stone, and the economic proportions of cement to sand which will give the density and plasticity of mortar required on the particular concrete job, should first be determined; and the table may then be applied to show the amount of coarse aggregate to be used.

For example, suppose that a mortar mixture of 1 part cement to 2½ parts sand (1:2½) is decided upon, and that the available coarse ag-

TABLE VIII

Proportions of Aggregates Giving Maximum Density with Varying Mixtures of Cement and Sand

Voids in Stone (Per Cent)	Proportions of Mortar									
	1 : 1	1 : 2	1 : 2½	1 : 3	1 : 3½	1 : 4	1 : 4½	1 : 5	1 : 5½	1 : 6
	Proportions of Stone									
20	5	10	12½	15	17½	20	22½	25	27½	30
21	4¾	9½	12	14¼	16⅔	19	21½	23¾	26¼	28½
22	4⅝	9	11⅓	13⅔	16	18¼	20½	22¾	25	27¼
23	4⅛	8⅔	10¾	13	15¼	17½	19½	21¾	24	26
24	4	8⅓	10½	12½	14⅔	16⅔	18¾	20¾	23	25
25	4	8	10	12	14	16	18	20	22	24
26	3¾	7⅔	9⅔	11½	13½	15⅓	17⅓	19¼	21¼	23
27	3½	7⅓	9¼	11	13	14¾	16⅔	18½	20⅓	22¼
28	3½	7¼	9	10¾	12½	14¼	16	17¾	19⅔	21½
29	3½	7	8⅔	10⅓	12	13¾	15½	17¼	19	20⅔
30	3⅓	6⅔	8⅓	10	11⅔	13⅓	15	16⅔	18⅓	20
31	3¼	6½	8	9⅔	11⅓	13	14½	16	17¾	19⅓
32	3	6¼	7¾	9⅓	11	12½	14	15½	17¼	18¾
33	3	6	7½	9	10⅔	12	13½	15¼	16⅔	18¼
34	3	6	7⅓	8¾	10¼	11¾	13¼	14¾	16¼	17⅔
35	2¾	5¾	7¼	8½	10	11½	12¾	14¼	15¾	17¼
36	2¾	5½	7	8⅓	9¾	11	12½	14	15¼	16⅔
37	2⅔	5⅓	6¾	8	9½	10¾	12¼	13½	14¾	16¼
38	2⅔	5¼	6½	8	9¼	10½	11¾	13¼	14½	15¾
39	2½	5	6⅓	7⅔	9	10¼	11½	12¾	14	15⅓
40	2½	5	6¼	7½	8¾	10	11¼	12½	13¾	15
41	2½	4¾	6	7⅓	8½	9¾	11	12¼	13½	14⅔
42	2⅓	4¾	6	7¼	8⅓	9½	10¾	12	13	14¼
43	2⅓	4⅔	5¾	7	8¼	9⅓	10½	11⅔	12¾	14
44	2¼	4½	5⅔	6¾	8	9	10¼	11⅓	12½	13⅔
45	2¼	4½	5½	6⅔	7¾	8¾	10	11	12¼	13⅓
46	2¼	4⅓	5½	6⅓	7⅔	8⅔	9¾	10¾	12	13
47	2¼	4⅓	5⅓	6⅓	7½	8½	9½	10⅔	11¾	12¾
48	2	4	5¼	6¼	7⅓	8⅓	9⅓	10½	11½	12½
49	2	4	5	6¼	7¼	8¼	9¼	10¼	11¼	12¼
50	2	4	5	6	7	8	9	10	11	12
51	2	3¾	5	6	6¾	7¾	8¾	9¾	10¾	11¾
52	2	3¾	4¾	5¾	6¾	7⅔	8⅔	9⅔	10½	11½
53	2	3⅔	4¾	5⅔	6⅔	7½	8½	9½	10⅓	11¼
54	1¾	3½	4⅔	5½	6½	7⅓	8⅓	9¼	10¼	11
55	1¾	3½	4½	5½	6⅓	7¼	8¼	9	10	11
56	1¾	3½	4½	5⅓	6¼	7¼	8	9	9¾	10¾
57	1¾	3½	4⅓	5¼	6¼	7	8	8¾	9⅔	10½
58	1¾	3½	4⅓	5¼	6	7	7¾	8⅔	9½	10⅓
59	1⅔	3⅓	4¼	5	6	6¾	7⅔	8½	9⅓	10¼
60	1⅔	3⅓	4	5	5¾	6⅔	7½	8⅓	9¼	10

gregate contains 33 per cent of voids. Then, looking at the table, starting at 33 in the void column at the left, and passing over to the right until we come to the proportion column headed 1:2½, we find 7½, which is the number of parts of stone to be added to the 1:2½ mortar mixture.

TESTING OF CEMENT

The most accurate and thorough tests of cement are those which are made in professional testing laboratories. These, however, are not always available; and fortunately they are not always necessary. In large constructions such as public works, and in smaller structures where very important values are at stake, laboratory tests are invariably insisted on. In all ordinary work, however, simpler tests, calling for no very elaborate apparatus and requiring no great degree of technical training, will be quite sufficient for practical purposes.

In careful technical supervision of processes of manufacture, and consequently in uniformity and reliability of product, the standard American brands of cement have no equals anywhere. There is, however, a possibility that now and then some small part at least of the output of the cement plant may fall below the regular standard in quality; and for that reason, on all important work, samples should be taken from every shipment—in fact, a sample from every barrel—and these samples should be tested with sufficient care at least to determine the presence or absence of any radical defects which would render the material unfit for use.

The methods of testing briefly described below, are in substance those recommended by the Committee on Uniform Tests of Cement, of the American Society of Civil Engineers.

Samples for Testing. Enough samples should be taken to insure an average representation of the shipment. No rule can be laid down as to how many; that will depend on the size and importance of the work.

The samples should be freed from lumps and foreign material by being passed through a sieve having 20 meshes per linear inch. This is also an effective method of mixing several samples from the same shipment to obtain an average. Where time will permit, however, the samples should be tested separately, as in this way uniformity, or the lack of it, will be most accurately shown. Samples removed from barrels or bags should extend from the surface well toward the center of the package.

Chemical Analysis. A chemical analysis should show the presence of adulterants, such as slag, stone dust, or other inert materials, if these happen to be present in any considerable quantity. It may also show the presence of certain active constituents, such as magnesia and sulphuric anhydride, in harmful excess, though opinions differ as to the proportions of these which are admissible. Up to 5 per cent of magnesia and 1.75 per cent of anhydrous sulphuric acid will probably do no harm.

A determination of the principal constituents of cement—lime, silica, alumina, iron oxide—should not be insisted on as a conclusive indication of quality, for these may safely vary within comparatively wide limits. Imperfect prepara-

tion of the raw material (such as insufficient fineness of grinding), or defective burning, is most frequently the cause of the trouble. Cement made from very finely ground material, and thoroughly burned, may contain much more lime than the amount usually present, and still be perfectly sound. On the other hand, cements low in lime may, on account of careless preparation of the raw material, be of dangerous character. Further, the ash of the fuel used in burning may so greatly modify the composition of the product as largely to destroy the significance of the results of analysis. All chemical analyses, therefore, should be supplemented by physical tests.

Specific Gravity. The specific gravity of cement is lowered by adulteration and hydration, but the adulteration must be in considerable quantity to affect the results appreciably. Differences in the specific gravity of cement are usually very slight, so that great care must be taken in making the tests.

The most convenient apparatus for determining specific gravity is that devised by Le Chatelier, a French engineer, and illustrated in Fig. 2. It consists of a flask D, of 120 cubic centimeters (7.32 cubic inches) capacity, the neck of which is about 20 centimeters (7.87 inches) long. In the middle of this neck is a bulb C, above and below which are two marks F and E, the volume between which is 20 cubic centimeters (1.22 cubic inches). The neck has

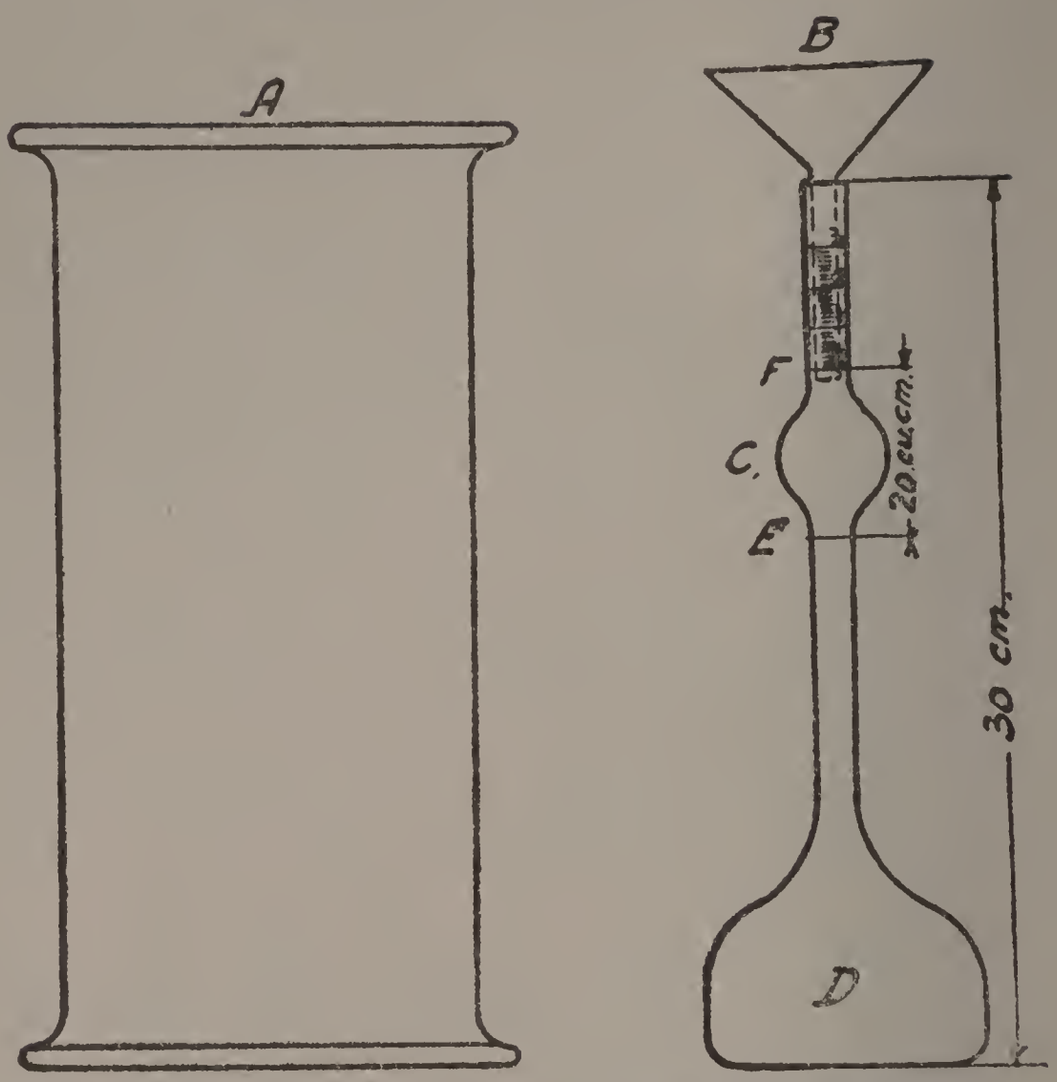


Fig. 2. Le Chatelier's Apparatus for Determining Specific Gravity of Cement.

a diameter of about 9 millimeters (0.35 inch), and is graduated into tenths of cubic centimeters above the mark F. Benzine (62 degrees Baumé naphtha), or kerosene free from water, should be used in making the test.

There are two methods of procedure:

(1) The flask is filled with either liquid to the lower mark E. Take 64 grams (2.25 oz.) of the cement to be tested, previously dried at 100 degrees C. (212 degrees F.), and cooled to the temperature of the liquid; and gradually pour it into the flask through the funnel B

(the stem of which reaches down to top of bulb C) until the upper mark F is reached. The difference in weight between the cement remaining and the original quantity (64 grams), is the weight which has displaced 20 cubic centimeters.

(2) Or the whole quantity of the powder may be introduced, causing the level of the liquid to rise to some division of the graduated neck. This reading, plus 20 cu. cm., is the volume displaced by 64 grams of the cement.

Water might just as well be used as benzine or kerosene, were it not for its chemical activity in connection with cement. If water were used, the cement would undergo radical changes and would not displace an equivalent volume of water.

The specific gravity is then obtained by dividing the weight of cement (in grams) by the displaced volume (in cubic centimeters), for the weight of a gram is approximately the same as that of a cubic centimeter of water.

During the operation, the flask is kept immersed in water in the jar A, to preserve a uniform temperature in the liquid.

The determination should be made on the cement as received; and should it fall below 3.10, a second determination should be made on the sample ignited (that is, exposed to a blast flame for, say, 15 minutes) at a low, red heat.

The results of tests of specific gravity may help to detect adulteration. In themselves, however, they are not necessarily conclusive as an indication of the quality of a cement, but, in

combination with the results of other tests, may afford valuable indications.

Fineness. It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and still produce a mortar of a given strength.

The degree of pulverization is ascertained by measuring the residue retained on certain **sieves.** Those known as the "No. 100" and "No. 200" sieves are recommended for this purpose. The sieves should be made of brass wire cloth; and should be circular, about 20 cm. (7.87 in.) in diameter, 6 cm. (2.36 in.) high, and provided with a pan 5 cm. (1.97) in. deep, and a cover. The wire cloth in the No. 100 sieve contains 96 to 100 meshes to the linear inch; in the No. 200 sieve, 188 to 200 meshes, giving respectively about 10,000 and about 40,000 meshes to the square inch. A quantity weighing 50 grams (1.76 oz.) or 100 grams (3.52 oz.), dried at 100 degrees C. (21 degrees F.) should be used for the test.

As mechanical sieving is not so practicable or efficient as hand sieving, the following is the method of procedure:

The thoroughly dried and coarsely screened sample is weighed, and placed on the No. 200 sieve, which, with pan and cover attached, is

held in one hand in a slightly inclined position, and moved forward and backward, the side being at the same time struck gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation is continued until not more than one-tenth of 1 per cent passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve, and the operation repeated. The work may be expedited by placing in the sieve a small quantity of steel shot. The results should be reported to the nearest tenth of 1 per cent.

Normal Consistency. The use of a proper percentage of water in mixing the pastes (mix-

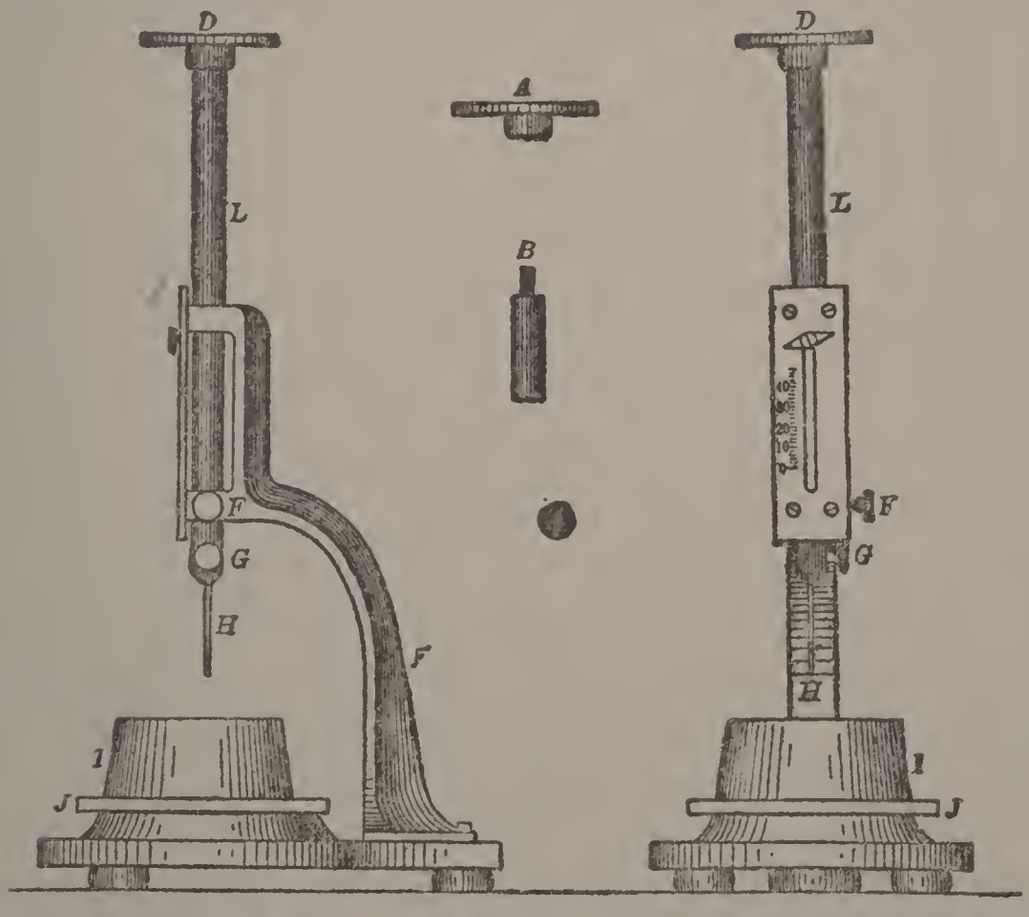


Fig. 3. Front and Side Views of Vicat Needle Apparatus for Testing Cement.

tures of cement and water) on which tests are made for time of setting, soundness, strength, etc., is of great importance, as it affects vitally the results obtained. The quantity of water should be just sufficient to reduce the cement to a certain state of plasticity, known as **normal consistency.** Various methods have been proposed for making this determination, none of which has been found entirely satisfactory. The Committee recommends the use of the **Vicat needle apparatus** for this purpose.

This consists of a frame K, Fig. 3, bearing a movable rod L, with the cap A at one end, and at the other the cylinder B, 1 cm. (0.39 in.) in diameter, the cap, rod, and cylinder weighing 300 grams (10.58 oz.). The rod, which can be held in any desired position by a screw F, carries an indicator, which moves over a scale (graduated to centimeters) attached to the frame K. The paste is held by a conical, hard-rubber ring I, 7 cm. (2.75 in.) in diameter at the base, 4 cm. (1.57 in.) high, resting on a glass plate J, about 10 cm. (3.94 in.) square.

In making the determination, the same quantity of cement as will subsequently be used for each batch in making briquettes for testing strength (but not less than 500 grams), is kneaded into a paste in the manner described below under the heading "Mixing for Tests." This paste is quickly formed into a ball with the hands, the operation being completed by tossing the ball six times from one hand to the

other, maintained 6 inches apart. The ball is then pressed into the rubber ring, through the larger opening, smoothed off, and placed (on its large end) on a glass plate, and the smaller end smoothed off with a trowel. The paste, confined in the ring, resting on the plate, is then placed under the rod bearing the cylinder, which is brought in contact with the surface, and quickly released.

The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 in.) below the top of the ring. Great care must be taken to fill the ring exactly to the top.

The trial pastes are made with varying percentages of water until the correct consistency is obtained.

The Committee has recommended, as normal, a paste the consistency of which is rather wet, because it believes that variations in the amount of compression to which the briquette is subjected in moulding are likely to be less with such a paste.

Having determined in this manner the proper percentage of water required to produce a paste of normal consistency, the proper percentage required for the mortars is obtained from an empirical formula.

The determination of such a formula is a matter on which no universal and final agreement has yet been reached. In the meantime, until a standard formula has been worked out,

the amount of water to be used may be taken as that indicated in Table IX, which shows the percentage of water required for a 1 : 3 mixture. This percentage will vary, where different cements are used, according to the percentage that may be necessary for giving normal consistency to the neat cement paste, as already determined.

TABLE IX

Percentage of Water for Standard Sand Mortars

Neat	One Cement Three Standard Ottawa Sand	Neat	One Cement Three Standard Ottawa Sand
15	8.0	27	10.0
16	8.2	28	10.2
17	8.3	29	10.3
18	8.5	30	10.5
19	8.7	31	10.7
20	8.8	32	10.8
21	9.0	33	11.0
22	9.2	34	11.2
23	9.3	35	11.5
24	9.5	36	11.5
25	9.7	37	11.7
26	9.8	38	11.8

For example, if the neat cement requires 18 per cent of water for normal consistency, then 8.5 per cent of water will be needed for the 1 : 3 mortar mixture. The percentages of water indicated are percentages **by weight**, being based on the weight of the dry material.

Time of Setting. The object of this test is to determine the time which elapses from the moment water is added until the paste ceases to be fluid and plastic (called the **initial set**), and also the time required for it to acquire a certain degree of hardness (called the **final** or **hard set**). The former of these is the more important, since,

FINISHING END OF PORTLAND CEMENT MILL UNDER CONSTRUCTION AT MONOLITH, CALIFORNIA.

To manufacture cement for water supply system of Los Angeles.

PORTLAND CEMENT KILNS OVER SIXTY YEARS OLD.

Located at Northfleet, Kent, England. The cement works at this place were founded by William Aspdin, son of Joseph Aspdin, the original inventor and patentee of Portland cement. He was a pioneer in the manufacture of cement in the Thames district, the kiln in the foreground being built by him in 1848. These kilns are of the upright or dome type, with intermittent draft.

POTTERY OF THE MOUND BUILDERS.

Found in Arkansas. The white specks are pieces of powdered clamshells, mixed with the clay. When clamshells were not available, sand was used in mixing the plastic material. See Page 10.

IONIC CAPITAL MOULDED IN CONCRETE.

ORNAMENTAL SHAPES OF CONCRETE.

with the commencement of setting, the process of crystallization or hardening may be said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and moulding or incorporating the mortar into the work, before the cement begins to set.

It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters. For this purpose the Vicat needle, already described, should be used. A paste of normal consistency is moulded and placed under the rod L, Fig. 3, this rod bearing the cap D at one end, and the needle H, 1 mm. (0.039 in.) in diameter, at the other, weighing 300 grams (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste, and quickly released.

The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 in.) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

The test pieces should be stored in moist air during the test. This is accomplished by placing them on a rack over water contained in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet.

Care should be taken to keep the needles clean, as the collection of cement on the sides of the needle retards the penetration, while cement

on the point reduces the area and tends to increase the penetration.

The determination of the time of setting is only approximate, being materially affected by the temperature of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of moulding the paste receives.

Sand for Testing. The sand recommended as standard for testing purposes, should pass a 20-mesh sieve, and leave not over 1 per cent on a 30-mesh sieve after one minute of continuous sifting. These requirements are met by the natural sand from Ottawa, Ill., as before explained.

Briquettes for Testing. The form and dimensions of briquettes for testing are indicated in Fig. 4. The moulds for the briquettes should be strongly made of brass, bronze, or other material equally resistant to corrosion, and should be wiped with an oily rag before using. Gang moulds, permitting several briquettes to be made at one time, are preferable to single moulds, as the greater quantity of mortar that can be mixed tends to give greater uniformity in the results.

Mixing for Tests. All proportions should be stated **by weight**; the quantity of water to be used should be stated as a **percentage of the dry material.**

The metric system is recommended because of the convenient relation of the gram and the

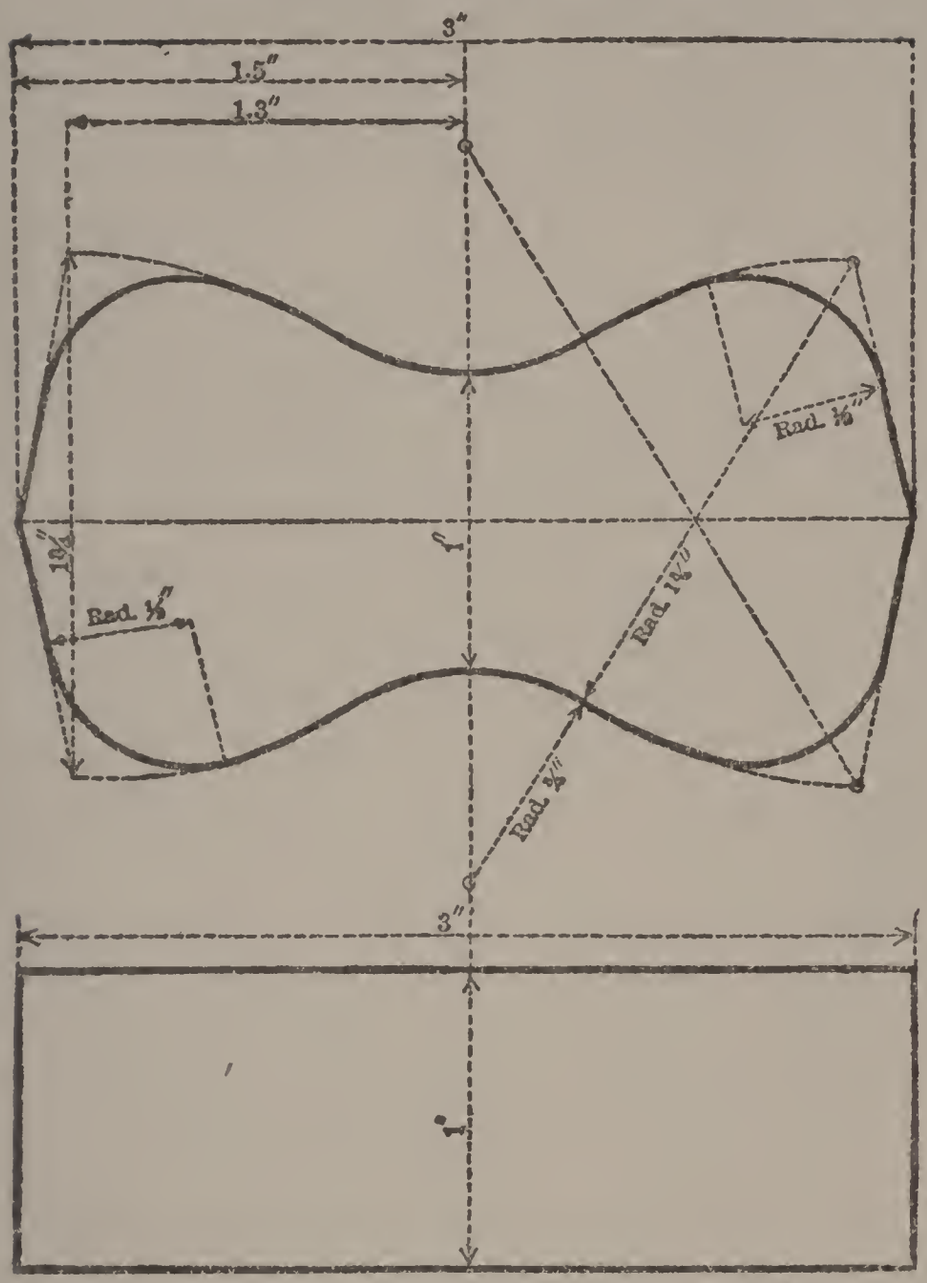


Fig. 4. Details of Cement Briquette for Testing.

cubic centimeter, one gram (the metric unit of weight) being approximately equal to the weight of 1 cubic centimeter of pure water at its maximum density.

The temperature of the room and the mixing water should be as near 21 degrees C. (70 degrees F.) as it is practicable to maintain it.

The sand and cement should be thoroughly mixed dry. The mixing should be done on some

non-absorbing surface, preferably plate glass. If the mixing must be done on an absorbing surface, it should be thoroughly dampened prior to use.

The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1,000 grams (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

The Committee, after investigation of the various mechanical mixing machines, has decided not to recommend any machine that has thus far been devised, for the following reasons:

(a) The tendency of most cement is to "ball up" in the machine, thereby preventing the working of it into a homogeneous paste.

(b) There are no means of ascertaining when the mixing is complete, without stopping the machine.

(c) It is hard to keep the machine clean.

The material is weighed, and placed on the mixing table. A crater is formed in the center, into which the proper percentage of clean water is poured; the material on the outer edge is turned into the crater by the aid of a trowel. As soon as the water has been absorbed, which should not require more than one minute, the operation is completed by vigorously kneading with the hands for an additional 1½ minutes, the process being similar to that used in kneading dough. A sand-glass affords a convenient guide for the time of kneading. During the

operation of mixing, the hands should be protected by gloves, preferably of rubber.

Moulding. Having worked the paste or mortar to the proper consistency, it is at once placed in the moulds by hand. The material should be pressed in firmly with the fingers, and smoothed off with a trowel, without ramming. The material should be heaped up on the upper surface of the mould; and, in smoothing off, the trowel should be drawn over the mould in such a manner as to exert a moderate pressure on the excess material. The mould should then be turned over, and the operation repeated.

A check upon the uniformity of the mixing and moulding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent from the average, should not be tested.

Storage of Test Pieces. During the first 24 hours after moulding, the test pieces should be kept in moist air to prevent them from drying out. A **moist closet** or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with a damp cloth—as is commonly done—is objectionable because the cloth may dry out unequally, in which case the test pieces are not all maintained under the same conditions. Where a moist closet is not available, a cloth may be used, but should be kept uniformly wet by immersing the ends in water. It should also

be kept from direct contact with the test pieces, by means of a wire screen or some similar arrangement.

A moist closet consists of a soapstone or slate box, or a metal-lined wooden box, the metal lining being covered with felt, and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist.

After 24 hours in moist air, the test pieces for longer periods of time should be immersed in water maintained as near 21 degrees C. (70 degrees F.) as practicable; they may be stored in tanks or pans, which should be of non-corrodible material.

Tensile Strength. Tests for tensile strength may be made on any standard **testing machine.** Solid metal clips of the form shown in Fig. 5 are recommended. The clips should be used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be ¼ inch wide, and the distance between the centers of contact on the same clip should be 1¼ inches.

Test pieces should be tested to the point of failure or rupture, as soon as they are removed from the water. Care should be observed to center the briquettes in the testing machine, as cross-strains, produced by improper centering, tend to lower the breaking strength. The load should not be applied too suddenly, as it may

produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquette be clean

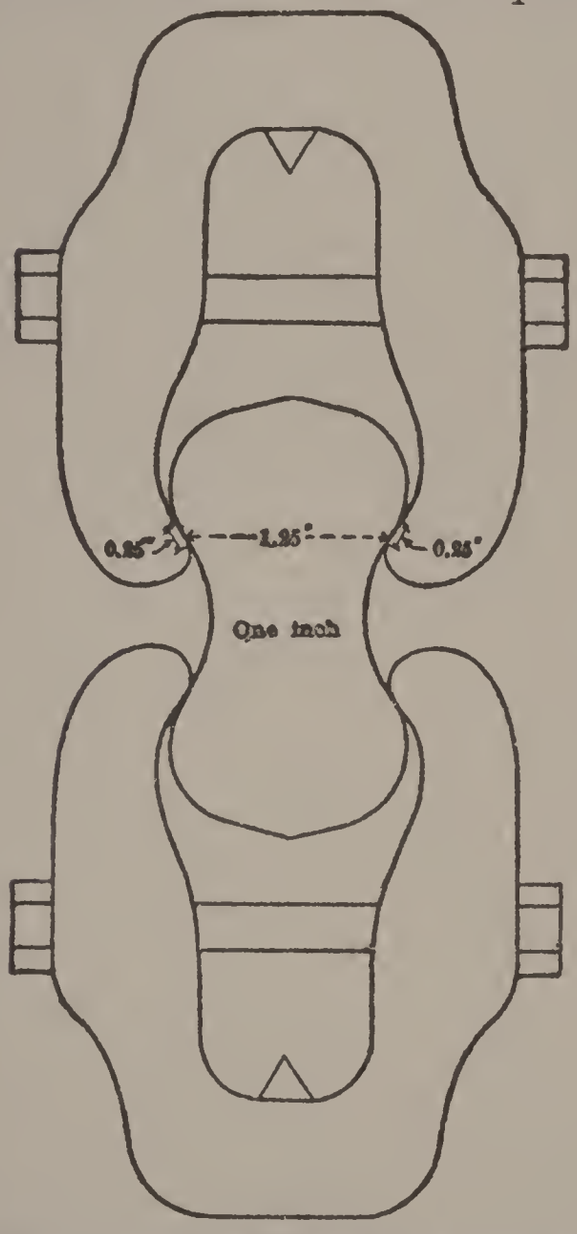


Fig. 5. Form of Clip Used for Holding Cement Briquette in Test for Tensile Strength.

and free from grains of sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 lbs. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding

any of the results which are manifestly faulty.

Constancy of Volume. The object of this test is to detect those qualities—if any are present—which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are generally made in a very short time, and are known, therefore, as **accelerated tests.** Failure is revealed by **cracking, checking, swelling, distortion,** or **disintegration,** or all of these phenomena. A cement which remains perfectly **sound** is said to be **of constant volume.**

Tests for constancy of volume are divided into two classes: (1) **Normal tests,** or those made in either air or water maintained at about 21 degrees C. (70 degrees F.); and (2) **Accelerated tests,** or those made in air, steam, or water at a temperature of 45 degrees C. (115 degrees F.) and upward. The test pieces should be allowed to remain 24 hours in moist air before immersion in water or steam, or preservation in air.

For these tests, pats about 7½ cm. (2.95 in.) in diameter, 1¼ cm. (0.49 in.) thick at the center, and tapering to a thin edge, should be made, upon a clean glass plate about 10 cm. (3.94 in.) square, from cement paste of normal consistency. In making the pats, the greatest care should be exercised to avoid initial strains due to moulding or to too rapid drying-out during the first 24 hours. The pats should be preserved

under the most uniform conditions possible, and rapid changes of temperature should be avoided.

In the normal test, a pat is immersed in water maintained as near 21 degrees C. (70 degrees F.) as possible, for 28 days, and observed at intervals. A similar pat, after 24 hours in moist air, is maintained in air at ordinary temperature, and observed at intervals.

In the accelerated test, a pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for 5 hours. To accomplish this, the use of the apparatus illustrated in detail in Fig. 6 is recommended.

To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion, or disintegration. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

In the present state of our knowledge, it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests; nor can a cement be considered entirely satisfactory simply because it has passed these tests. Accelerated tests, therefore, are to be taken merely as precautionary measures, not as infallible and final guides. Should a cement fail to meet the requirements of the accelerated test, it may be kept for 28 days, and then tested again. Failure at this time would probably indicate sufficient cause

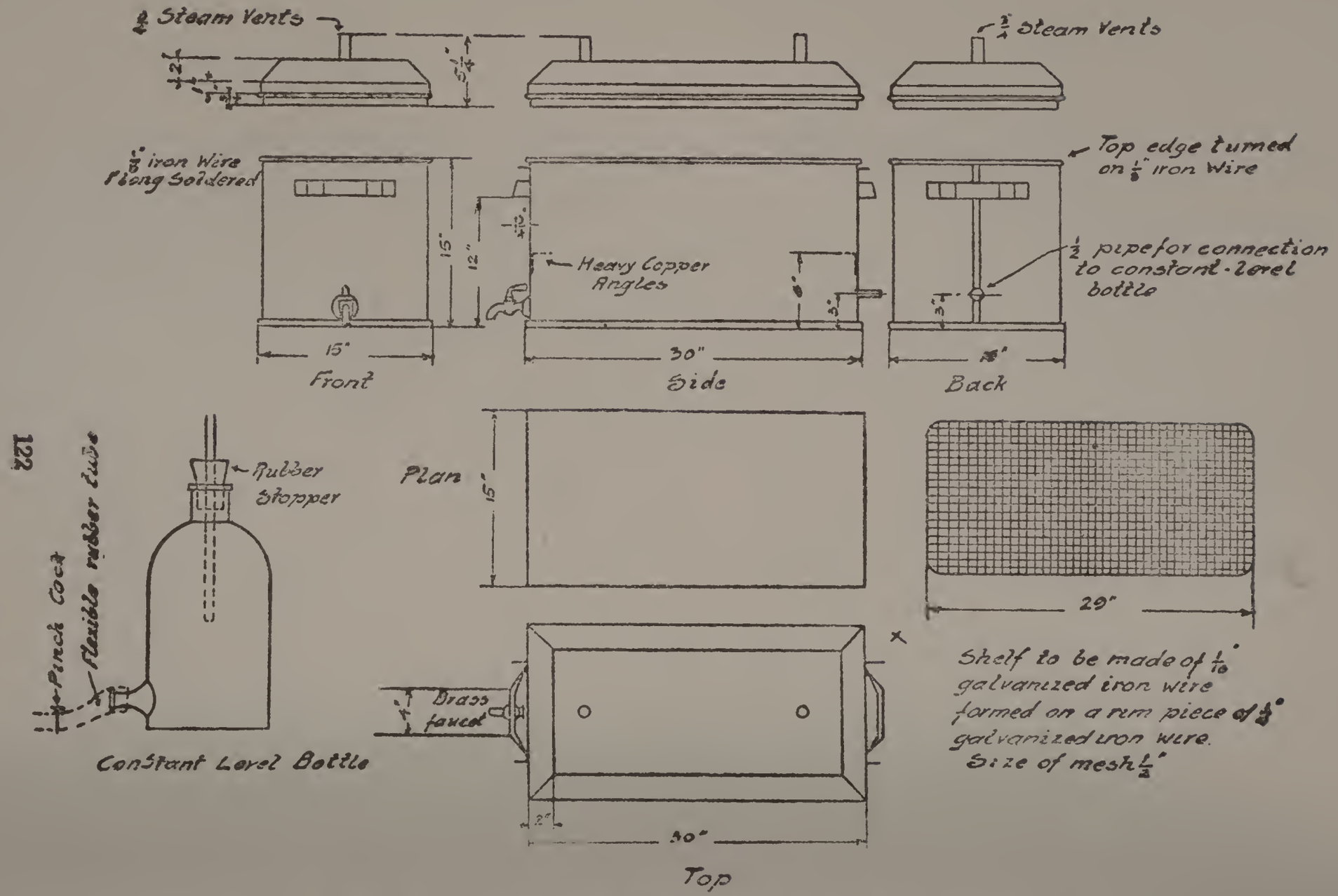


Fig. 6. Apparatus for Making Accelerated Test of Cement.

Copper boiler to be made of sheet copper weighing 22 oz. per square foot, tinned inside. All seams to be lapped where possible, and only hard solder to be used.

for rejection, though passing the test—as already noted—would not necessarily indicate perfect soundness, and the result of other tests should also be taken into consideration.

STANDARD SPECIFICATIONS FOR CEMENT

The requirements which a cement must meet in order to be recognized as of "standard" quality, are outlined by the Committee on Standard Specifications for Cement, of the American Society for Testing Materials, in substance as follows:

General Conditions. All cement shall be inspected—either at the place of manufacture or on the work.

In order to allow ample time for inspecting and testing, the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground, and should be easy of access for proper inspection and identification of each shipment.

Every facility shall be provided by the contractor, and a period of at least twelve days allowed for the inspection and necessary tests.

Cement shall be delivered in suitable packages, with the brand and name of manufacturer plainly marked thereon.

A bag of cement shall contain 94 pounds of cement, net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural

cement shall contain 3 bags of the above net weight.

Cement failing to meet the 7-day requirements may be held awaiting the results of the 28-day tests before rejection.

All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement, of the American Society of Civil Engineers (see above).

The acceptance or rejection shall be based on the following requirements:

Specifications for Natural Cement

Fineness. A natural cement shall leave by weight a residue of not more than 10 per cent on the No. 100, and 30 per cent on the No. 200 sieve.

Time of Setting. It shall not develop initial set in less than 10 minutes, and shall not develop hard set in less than 30 minutes, or in more than 3 hours.

Tensile Strength. The minimum requirements for tensile strength for briquettes one inch square in cross-section, shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT

Age	Strength
24 hours in moist air	50-100 lbs.
7 days (1 day in moist air, 6 days in water)	100-200 "
28 days (1 day in moist air, 27 days in water)	200-300 "

ONE PART CEMENT, THREE PARTS STANDARD SAND

7 days (1 day in moist air, 6 days in water)	25- 75 lbs.
28 days (1 day in moist air, 27 days in water)	75-150 "

For example, the minimum requirement for the 24-hour neat cement test should be some specified value within the limits of 50 and 100 pounds; and so on for each period stated.

If the minimum strength is not specified, the mean of the above values shall be taken as the minimum strength required.

Constancy of Volume. Pats of neat cement about three inches in diameter, one-half inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hours. One pat shall then be kept in air at normal temperature; and another kept in water maintained as near 70 degrees F. as practicable.

These pats are observed at intervals for at least 28 days, and, to satisfactorily pass the tests, should remain firm and hard, and show no signs of distortion, checking, cracking or disintegration.

Specifications for Portland Cement

Specific Gravity. The specific gravity of the cement, ignited at a low red heat, shall be not less than 3.10, and the cement shall not show a loss in weight, on ignition, of more than 4 per cent.

To determine the loss on ignition, place half a gram of cement in a platinum crucible, set in a hole in an asbestos board so that about three-fifths of the crucible projects below the board. Expose the crucible to blast flame for 15 min-

utes, preferably with an inclined flame. The loss, found on weighing, should be checked by a second blasting of 5 minutes.

Fineness. The cement shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

Time of Setting. It shall not develop initial set in less than 30 minutes, and must develop hard set in not less than 1 hour, nor more than 10 hours.

Tensile Strength. The minimum requirements for tensile strength for briquettes one inch square in section, shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT

Age	Strength
24 hours in moist air	150-200 lbs.
7 days (1 day in moist air, 6 days in water)	450-550 "
28 days (1 day in moist air, 27 days in water)	550-650 "

ONE PART CEMENT, THREE PARTS SAND

7 days (1 day in moist air, 6 days in water)	150-200 lbs.
28 days (1 day in moist air, 27 days in water)	200-300 "

For example, the minimum requirement for the 24-hour neat cement test should be some specified value within the limits of 150 and 200 pounds; and so on for each period stated.

If the minimum strength is not specified, the mean of the above values shall be taken as the minimum strength required.

Constancy of Volume. Pats of neat cement about three inches in diameter, one-half inch

thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours. One pat shall then be kept in air at normal temperature, and observed at intervals for at least 28 days. Another pat shall be kept in water maintained as near 70 degrees F. as practicable, and observed at intervals for at least 28 days. A third pat shall be exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for 5 hours (see Fig. 6).

These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking, cracking, or disintegration.

Sulphuric Acid and Magnesia. The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

Easily-Made Testing Apparatus

Mr. W. Purves Taylor, engineer of the Municipal Testing Laboratories of Philadelphia, Pa., has devised simple methods of testing that in a general way are suited to the requirements of cement users, and for which all the necessary apparatus can easily be made by anyone of ordinary mechanical ability. These simple methods of testing are described as follows:

Soundness. Take about half a pound of cement, place it on a clean surface of metal or

glass, and form it into a crater. Into the center of the crater pour about a fifth of its weight of water, and mix thoroughly by hand or with a trowel for a couple of minutes, until a stiff and uniform paste is obtained. Make a ball of the paste about 2 inches in diameter, and drop it on the table from a height of about 2 feet. If the ball flattens more than half its depth, the paste is too wet; if it cracks badly, it is too dry. If necessary, add more cement or more water, mix thoroughly, and test until the right consistency is obtained; then mould two balls about 2 inches in diameter.

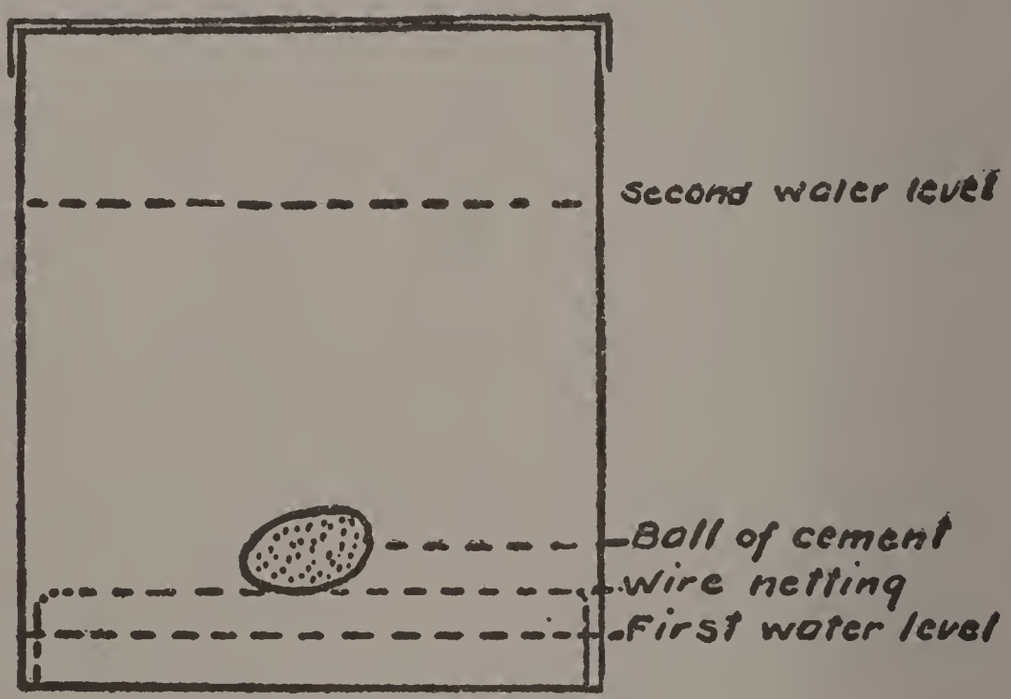


Fig. 7. Method of Testing for Soundness.

Take a tin can which has a tightly fitting cover, and bend into it a piece of wire netting, as shown in Fig. 7, about 2 inches from the bottom. Put about an inch of water in the bottom of the can, place one of the balls on the netting, cover the can, and put it away in a cool place

ORNAMENTAL SEAT MOULDED IN CONCRETE.

JARDINIERE, BENCH, AND SEATS MOULDED IN CONCRETE.
Studio of T. A. Rowley, Chicago, Ill.

ARTISTIC EFFECTS IN LANDSCAPE DECORATION, LAKE PARK, MILWAUKEE, WISCONSIN.

QUARRY OF CEMENT ROCK USED IN MANUFACTURE OF PORTLAND CEMENT.

for 24 hours. Then fill the can with water to cover the ball, remove the cover, and place the can on a stove at such a heat that the water will boil in about half an hour. Let it boil gently then for three hours. Have a second vessel of boiling water beside the can; and, as the water evaporates from the first vessel, replace it with the boiling water from the second one. **Never add cold water.** After boiling three hours, remove the ball, and examine it.

A good Portland cement will always pass this test, and the ball will remain sound and hard. If the ball is disintegrated, or if it is checked or cracked, it generally indicates inferior quality and untrustworthy material. Sometimes failure in boiling is caused by the material being too fresh, and, on a second test made a month or so later, the cement will pass, showing that the expansive elements have become hydrated and thus inert. In general, however, it is on the safe side never to use cement that fails in boiling. If it fails at first, store it away for a month, and then test again. If it still fails, it is better not to use it.

Time of Setting. Put the second ball, made as previously described, in a place protected from the sun or any other source of heat, and from any strong current of air. At the end of twenty minutes, examine it; then put it away, and examine it again in ten hours. The ball, at twenty minutes, should still be soft and pliable, damp on the surface, and should not feel

warm. At ten hours it should be dry, firm, and hard enough so that a firm pressure of the thumb nail will make no impression on it. If the cement begins to harden or feel warm in less than twenty minutes, it is generally inadvisable to use it, since setting will have begun before the mortar or concrete is moulded, and the result will be a weak and easily disintegrated product. It is, of course, possible to retemper such cement and obtain excellent results; but this process requires considerable skill and experience, and therefore is not usually to be recommended; moreover, it always means at least some slight loss in strength.

Quick-setting cement often becomes slower by storage for a month or two, so that it may be better to keep such material for that length of time than to attempt to use it earlier at the risk of poor results. A cement that does not harden in ten hours may ultimately give good results; but the slow setting will much delay the progress of the work, and may cause injury in removing the moulds or striking the centers. Safe practice will require cement to set between the stated limits.

Purity. Take as much cement as may be lifted on a five-cent piece, and place it in a china or glass dish. Pour on it a mixture of 1 part of water and 3 parts of muriatic (hydrochloric) acid, using a quantity equal to about three times the volume of cement. Pure Portland cement effervesces violently for a second or two, and

then forms a yellowish jelly. A continued effervescence shows adulteration with limestone or natural cement. Cinders or sand, if present, will be shown in a sediment at the bottom of the jelly. The presence of slag is shown by the characteristic putrid odor of hydrogen sulphide (sulphuretted hydrogen). Cement containing any of these adulterations or impurities should not be used.

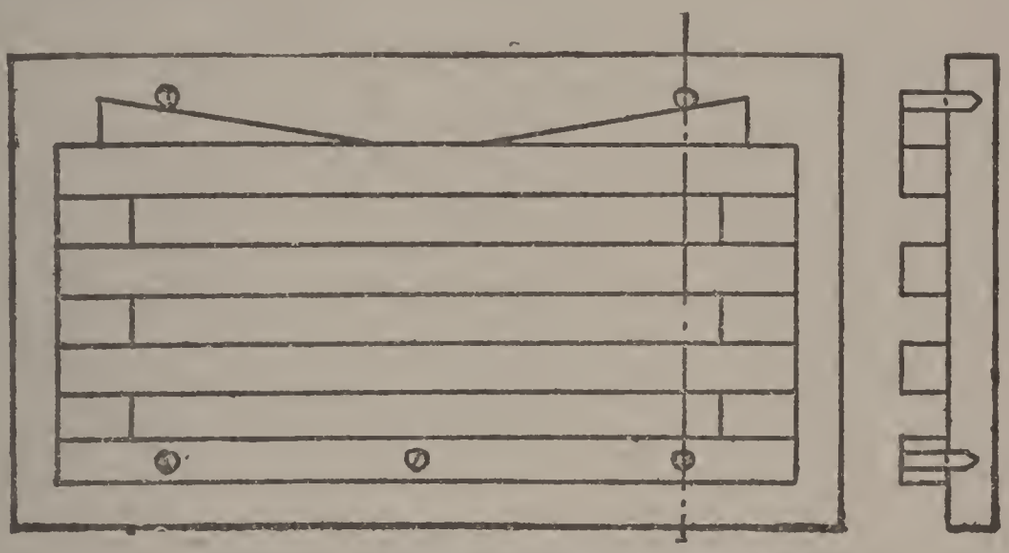


Fig. 8. Moulds for Simple Tests.

Strength. It is hard to determine the strength of a cement mortar by any simple method, and obtain results of even approximate accuracy. The following, however, is probably the best simple method:

Make a mould, as shown in Fig. 8, of a planed board and some one-inch strips of wood. Fasten the top strip to the board, and place the others on loosely, in the manner indicated in the diagram, holding them in place by the wedges at the bottom, thus forming moulds for three prisms or bars of mortar 1 inch by 1 inch by 12

inches long. Take special care that the cross sections of the prisms are exactly one square inch.

Take mortar from the mixing box, or make some of 1 part cement and 3 parts sand, thoroughly mixed dry and then wetted to form a stiff mortar; and fill the moulds, pressing the material in firmly, and smoothing the tops with a trowel. The moulds should be oiled slightly to prevent mortar from sticking. Put the moulds away in a cool and, if possible, a damp place, for 24 hours. Then remove the prisms of mortar, and place them in fresh water, neither hot nor cold, for 6 or for 27 days. Any prisms that are chipped or otherwise defective should be discarded. Make the apparatus shown in Fig. 9 with a board, a round piece of wood about an inch in diameter, and a pail. The bottom bearing edges are made by cutting the round piece of wood in half, and are fastened to the board exactly 10 inches apart, center to center. The center bearing is a round piece of wood from which a pail is suspended by a cord.

When the test pieces are 7 or 28 days old, place them, still wet, on the apparatus as shown in the cut, taking care that the upper strip is exactly in the center and at right angles with the prism. Adjust the pail so that it is just off the ground and exactly under the specimen; and then slowly pour sand into it until the prism breaks. Carefully weigh the bucket, with the cord and strip still attached; this will indicate

the **load** that stressed the bar to the failing point. If the prism is not exactly one inch square, correct the weight by dividing it by the product of its width times the square of its depth in inches.

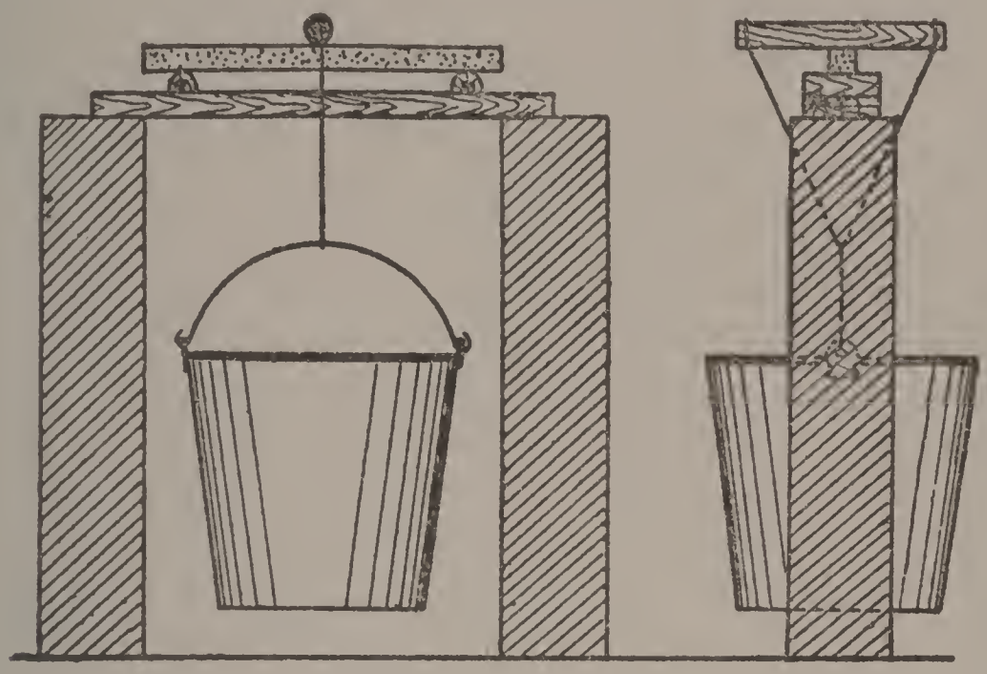


Fig. 9. Method of Testing Strength.

The approximate strength of the mortar may then be computed as follows:

Tensile strength equals center load multiplied by 10.

Compressive strength equals center load multiplied by 50.

If the average of three prisms tested in this manner shows a tensile strength of less than 120 pounds at 7 days, or 180 pounds at 28 days, on 1:3 mixture, something is radically wrong with either the cement or the sand, and the fault should be thoroughly investigated.

Tests made by this method are, of course, far from being accurate, but nevertheless give a

very fair indication of the value of the material. In determining the relative value of different sands intended for use, they will often give most valuable and useful information.

Crude as these tests may be said to be, they are vastly superior to no tests at all, and should be of much assistance to the small user in securing good material. **Insist on cement that will boil and set normally, and most of the dangers of inferior cement will be avoided.**

Another simple method of testing by which the user may ascertain the soundness of the cement he purposes to use, is as follows:

Make three cakes of cement, thicker in the middle than on the edges. Allow one to remain in moist air for 24 hours, and then steam it 4 hours. The second cake should be exposed in moist air, and the third be immersed in water. The results in the case of the second and third cakes should be noted at intervals during 28 days. If the cement is sound, it will not disintegrate; but if it shows expansion cracks on the edges of any of the cakes, it is not sound.

CHOICE OF CONCRETE MIXTURES

Having learned how to select good materials and how to proportion them so as to obtain concrete of any desired strength up to maximum, the next important requirement for the concrete worker is that he shall know how to decide upon the proper mixture to use for any particular kind of work.

Mixtures of greatly different strength and greatly different cost, as already explained, can be made from the same materials, by simply combining them in different proportions. The particular mixture to use will depend principally upon the **kind of service** that will be required of the concrete—upon whether it will have to bear heavy or light loads and withstand great or small stresses; whether or not it will be subjected to hard and rough wear; whether it is to be covered or left exposed, above ground or underground; whether it will have to withstand water pressure, etc. If a man, for example, builds a concrete sidewalk from the kitchen steps to the back gate, he will naturally require a different mixture from that he would use in making a water-tank or cistern; and for the face of the sidewalk he will hardly use the same coarse and cheap mixture that will serve very well for the sub-base. It is important, therefore, to know how to serve the purposes of economy as well as structural stability, in determining what mixtures shall be used in the different kinds of construction and even in different parts of the same work.

Kinds of Mixtures

Concrete mixtures are classified in two different ways—(1) as to **consistency**, or **relative wetness**; and (2) as to **richness**, or **relative quantity of cement.**

Wetness of Mixture. Classified according to relative wetness, there are three kinds of mixture commonly used in concrete work—namely, **Very Wet, Medium,** and **Dry.** Their distinguishing features are as follows:

Very Wet Mixture. Concrete wet enough to be mushy and to run off a shovel in handling. Used for reinforced work, such as thin walls, floors, or other thin sections, reinforced columns, tanks, conduits, etc. Practically no ramming is necessary, but spading should be done next to the forms, to insure burial of the coarser aggregate and the formation of an unbroken face by the cement grout.

Medium Mixture. Concrete just wet enough to make it jelly-like, so that it will quake on tamping. Used for some reinforced work, but chiefly for foundations, floors, and massive constructions, such as retaining walls, piers, abutments, arches, etc. Ramming with tamper or treading with feet necessary to remove air-bubbles and fill voids. A man stepping on a pile of this concrete would sink ankle-deep. Spading also necessary for same reason as in the very wet mixture.

Dry Mixture. Concrete like damp earth. Used for foundations, etc., where it is important that the concrete shall set as quickly as possible. Should be placed in layers 4 to 6 inches deep at a time, and thoroughly tamped until the water comes to the surface. In dry concrete, it is only by thorough tamping that the danger of the

formation of pockets which would weaken the concrete can be avoided. Careful spading should also be done next the forms.

The drier the mixture, the sooner the concrete will set. Any quantity of water that falls below the minimum necessary for thorough hydration of the cement, is, of course, not to be allowed in any case, for then the concrete would be weak and crumbly; but beyond this point the addition of more or less water does not seem to have any very important bearing upon the ultimate strength of the concrete, **provided the mixing is thoroughly done and the concrete properly deposited.** A liberal use of water, however, besides increasing plasticity and ease of working, renders easier the insuring of a thorough mixture and the securing of great density. In reinforced concrete work, a dry mixture is not at all satisfactory, since it is more difficult, and hence more costly, to handle than a wet mixture, will not penetrate and fill all spaces between the reinforcing steel members so as to insure the thorough bond that is required, must be protected with greater care from the sun or from drying too quickly, and, unless great skill is used in spading it, will show voids or pockets in the face of the work when the forms are removed. The prevailing tendency in present-day practice, therefore, is toward the medium or very wet mixtures.

In the specifications of the American Railway Engineering and Maintenance of Way Associ-

ation (1903), the required consistency of concrete is specified as follows:

"The concrete shall be of such consistency that when dumped in place it will not require tamping. It shall be spaded down, and tamped sufficiently to level off, and will then quake freely like jelly, and be wet enough on top to require the use of rubber boots by workmen."

Richness of Mixture. When classified according to relative richness in cement, concrete mixtures are distinguished under four different headings—namely, **Rich, Medium, Ordinary,** and **Lean.**

Rich Mixture. A 1:2:4 concrete—that is, a mixture containing ingredients in the proportion of 1 barrel (4 bags) of packed Portland cement just as it comes from the manufacturer, to 2 barrels (7.6 cubic feet) of loose sand, to 4 barrels (15.2 cubic feet) of loose gravel or broken stone—would be called a **rich mixture.** This gives a very strong concrete adapted to all kinds of reinforced work that will be subjected to very heavy loads and stresses, such as reinforced floors, arches, beams, girders, columns, foundations for heavy vibrating machinery, etc. It is also used where water-tightness and air-tightness are desired, as in the construction of reservoirs, water conduits, silos, tanks, cisterns, troughs, culverts, building walls, etc.

Medium Mixture. A 1:2.5:5 concrete—that is, in the proportions of 1 barrel (4 bags) Portland cement, to 2.5 barrels (9.5 cubic feet) loose

sand, to 5 barrels (19 cubic feet) loose gravel or broken stone—would be called a **medium mixture.** This also gives a very strong concrete, and is adaptable to ordinary machine foundations, thin foundation walls, building walls, arches, ordinary ground floors, sidewalks, gutters, sewers, culverts, etc.

Ordinary Mixture. A 1:3:6 concrete—that is, in the proportions of 1 barrel (4 bags) Portland cement, to 3 barrels (11.4 cubic feet) loose sand, to 6 barrels (22.8 cubic feet) loose gravel or broken stone—would be called an **ordinary mixture.** This gives a strong concrete, but of less strength than either a medium or a rich mixture. It is adaptable to massive work, such as heavy walls, retaining walls, piers, abutments, etc., which will be subjected to considerable strain. It is sometimes used for reinforced concrete in floors and walls; but is more generally used without reinforcement, in foundations, footings, ground floors, sidewalks, gutters, etc.

Lean Mixture. A 1:4:8 concrete—that is, in the proportions of 1 barrel (4 bags) Portland cement, to 4 barrels (15.2 cubic feet) loose sand, to 8 barrels (30.4 cubic feet) loose gravel or broken stone—would be called a **lean mixture.** This gives a concrete weak in tensile strength, but of considerable compressive strength, and therefore specially adaptable to comparatively unimportant massive work where the concrete will be subjected only to plain compressive strains, as in large and thick foundations sup-

porting stationary loads, backing for stone masonry, sub-bases for sidewalks, driveways, etc.

As a rough guide that will enable the concrete worker or contractor to tell at a glance approximately the kind of mixture appropriate for various classes of work, Table X has been compiled. The indications of mixtures given in the table must not be taken as exact and final specifications for any one of the particular kinds of work mentioned, but merely as approximate guides to what is average current practice. No hard and fast lines of universal application can be drawn which will set off certain mixtures as the only ones adaptable to certain kinds of work. The allowable mixtures are separated by no well-defined boundaries, but merge into one another by insensible degrees; and a considerable variation from the indicated proportions may not only be permissible in some cases, but may even be advisable for the sake of strength as well as of economy.

Variations Allowable in Mixtures. If, for example, the aggregates are well graded, and their proportions carefully determined by one of the methods before described, smaller proportions of cement may be used for each class of work. If, on the other hand, the sand is very fine, the quantity of cement should be increased 10 to 15 per cent. Instances of construction will occur in which the strength of concrete required for safety may be obtained from almost any mix-

TABLE X

Approximate Mixtures Adaptable to Various Classes of Work

Rich, 1:2:4; Medium, 1: 2.5:5; Ordinary, 1:3:6; Lean, 1:4:8

Kind of Work	Mixture	Consistency
Abutments	Rich to Ordinary	Medium
Arches	Rich to Medium	Medium
Backing for Masonry	Lean	Medium to Dry
Beams, Reinforced	Rich to Medium	Very Wet
" Plain	Rich to Medium	Very Wet to Medium
Cisterns	Rich to Medium	Very Wet to Medium
Columns, Reinforced	Rich	Very Wet
Conduits, Water	Rich	Very Wet
Coping	Rich to Medium	Medium
Culverts, Reinforced	Medium to Ordinary	Medium
" Plain	Medium to Ordinary	Medium
Driveways	Same as Sidewalks	
Fence Posts	Rich	Very Wet to Medium
Floors, Reinforced	Rich to Ordinary	Very Wet to Medium
" Ordinary Ground	Medium to Ordinary	Medium
Footings	Ordinary to Lean	Medium
Foundations, Heavy Vibrating Machinery	Rich	Very Wet to Medium
" Ordinary Machinery	Medium	Medium
" Thin Walls	Rich to Medium	Very Wet to Medium
" Thick Walls	Medium to Lean	Medium to Dry
Girders, Reinforced	Rich to Medium	Very Wet
" Plain	Same as Beams	
Gutters	Same as Sidewalks	
Pavements	Same as Sidewalks	
Piers	Rich to Ordinary	Medium
Reservoirs	Rich to Medium	Very Wet to Medium
Roof Slabs	Medium to Ordinary	Medium
Sewers, Reinforced	Rich to Medium	Medium
" Plain	Medium	Medium
Sidewalks (Base)	Medium to Ordinary	Medium to Dry
" (Sub-Base)	Ordinary to Lean	Medium to Dry
Silos	Rich to Medium	Very Wet to Medium
Tanks	Rich to Medium	Very Wet to Medium
Walls, Dwelling Houses	Rich to Medium	Very Wet to Medium
" Large Buildings (Compression and Tension)	Rich to Medium	Very Wet to Medium
" Large Buildings (Compression Only)	Medium to Ordinary	Medium
" Massive	Medium to Ordinary	Medium
" Retaining	Medium to Ordinary	Medium
" Thin Foundations	Rich to Medium	Very Wet to Medium
" Tunnel	Medium to Ordinary	Medium

ture ranging from lean to rich; and in such cases, choice of mixture will probably be dictated by considerations of cost or by empirical rules based on what has been found most advantageous in actual practice.

Measuring Out Quantities for Mixing

The problem of giving a table for measuring out exactly the proper quantities to be mixed together in making concrete, would be comparatively simple if a uniform standard were adopted for either the weight or the volume of the packages (barrels or bags) which are shipped by different manufacturers of cement. There is, however, no such thing as a **standard barrel** or a **standard bag,** both the weight and the size of these packages varying considerably with the different brands. A 1:2:4 mixture, using any one brand, will give a concrete differing somewhat from a mixture ostensibly the same in proportions, but using another brand. Moreover, a barrel of packed Portland cement is considerably increased in volume when dumped loose; and here again there will be some slight variation among the different brands. A barrel, for example, containing 3.5 to 3.8 cubic feet of packed cement will give a volume ranging somewhat over 4 cubic feet when dumped loose. It is therefore absolutely impossible to compile any working table indicating volumes and weights for mixtures which will be capable of universal application and which will at the same time insure an absolute uniformity of mixture irrespective of what brand of cement is used. Fortunately, however, the character of Portland cement concrete is such as to allow considerable leeway in the matter of proportioning; and

these small variations—unavoidable in general construction work—are not sufficient to affect seriously the quality or strength of the concrete. Moreover, it is always possible to be on the safe side.

Some authorities, for the sake of simplicity in proportioning and measuring, consider that 1 bag Portland cement=1 cubic foot=100 lbs., thus making 1 barrel=400 lbs. It is, however, a closer approach to actual facts as found in practice, to take the average weight of a barrel as 380 lbs., thus making the weight of a bag 95 lbs.

Throughout the present work, unless otherwise expressly stated, all proportions will be given **by volume, not by weight.**

Very often, in plain concrete work, such as foundation or sidewalk construction, the materials are measured from wheelbarrows or buckets whose capacities have been accurately determined, or in some other simple and fairly reliable manner. The use of more uniform and accurate methods of measuring, however, is recommended; and in all cases, measurements should at least be checked up—especially when there is any change in the quantity desired, as, for example, in batches requiring less than full wheelbarrow loads.

A convenient form of measuring box can be made from any kind of rough boards. It may be rectangular in shape with perpendicular sides, and should be provided with a short

handle at each corner (see Plate 3). It should have no top or bottom, being filled only at the place of mixing, and emptied by being simply lifted up. It should be of three or four cubic feet capacity, and may be graduated so that one, two, or more cubic feet can be accurately measured.

In measuring, **do not pack** or ram the material. Sand, gravel, and stone should be **measured loose.** Simply shovel in the loose material, strike off level across the top, and lift the box away.

Tables for Measuring Materials

The importance of the tables which engineers have compiled for the convenience of practical workers in all lines of construction, cannot be too strongly insisted upon. They are the richest fruitage of practical experience, being based on a great multitude of notes, measurements, and observations made in connection with actual examples of construction, and are veritable treasure-stores of practical, labor-saving information. It is not necessary for the ordinary worker in concrete, or steel, or any other form of material, to attempt the impracticable task of exploring all the highways and byways where the testing engineer finds himself at home. Tables are available which will cover every phase of every construction problem likely to be met with in ordinary practice; and a little familiarity with the use of these

JARDINIERES AND BENCH MOULDED IN CONCRETE.

GROUPS OF CONCRETE BLOCKS.

With modern machines, these blocks are now made in a great variety of plain and ornamental forms adaptable to a very wide range of structural details.

CEMENT BLOCK COTTAGE AT ALBION, ILL.

Blocks 16 in. long, faced and waterproofed; plaster applied directly to back side of blocks; porch floors of concrete; roof of tin shingles. Cottage contains seven rooms and basement.

CONCRETE BLOCK COTTAGE AT ASBURY PARK, NEW JERSEY.
Blocks, 8 by 8 by 16 inches.

tables will enable anyone to take advantage of the immense labors of others, and to bring to bear on any problem confronting him the results of the widest experience and the highest skill.

In measuring out the quantities required for mixing concrete, it may be necessary to proceed in different ways. We may, for example, have to mix in **small batches**, and shall need to know how much sand and gravel to lay out for two or three bags of cement at a time; or we may have to decide on the quantities as required **per cubic yard** of the space to be filled with concrete; etc.

Several tables will therefore be given, meeting these different conditions; and by reference to these tables the quantities required for any ordinary mixture can be determined almost at a glance.

Quantities for Batch Mixing. Tables XI and XII, compiled by Percy H. Wilson and Clifford W. Gaylord, show the quantities for a 2-bag batch. A 3-bag batch will require half as much more of each ingredient; a 4-bag batch, just double the amount; and so on. If the aggregates used are sand and crushed stone or gravel, use Table XI; if natural-bank sand and gravel already mixed, use Table XII.

From these tables the quantities required for batches of any size can easily be calculated in the manner above described. They will simply be increased or diminished in proportion with the cement. Thus the quantities indicated

TABLE XI

Quantities of Materials, and Resulting Amount of Concrete, for a Two-Bag Batch

Aggregates—Sand and Broken Stone or Screened Gravel

Mixture	Quantities of Material Required			Amount of Concrete Obtained	Size of Measuring Boxes (Inside Dimensions)		Water for Medium Wet Mixture
	Cement	Sand	Stone or Gravel	Cu. Ft.	Sand	Stone or Gravel	Gallons
	Bags	Cu. Ft.	Cu. Ft.				
1:2:4	2	3¾	7½	8½	2′ x 2′ x 11½″	2′ x 4′ x 11½″	10
1:3:6	2	5¾	11½	12	2′ x 3′ x 11½″	3′ x 4′ x 11½″	13½

by the tables—which are for 2-bag batches—would have to be doubled for a 4-bag batch; trebled for a 6-bag batch; etc.

Measure the water with a bucket. This will give more uniform results than using a hose. The number of gallons indicated in the tables is only approximate. Try it on the first batch; and if the mixture is made too wet, reduce the amount of water; if too dry, increase the amount, so as to get the desired consistency.

Suppose, for example, that we wish to construct a silo. This calls for a certain amount of rich mixture 1:2:4 (see Table X). If a natural mixture of sand and gravel is not obtainable, we shall have to mix these ingredients ourselves, possibly using crushed stone instead of gravel, and shall therefore have to use Table XI. If, on the other hand, a natural bank of sand and gravel is near by, we shall take our aggregate from that, and in that case shall use Table XII.

Assume the latter case. We shall probably have first to screen out the excess of fine material so as to get a well-graded aggregate, for natural mixtures ordinarily contain far too

TABLE XII

Quantities of Materials, and Resulting Amount of Concrete, for a Two-Bag Batch

Aggregate—A Natural Mixture of Sand and Gravel

Mixture	Proportions by Parts		Quantities of Material Required		Amount of Concrete Obtained	Size of Measuring Boxes (Inside Dimens'ns)	Water for Medium Wet Mixture
	Cement	Natur'l Mixture of Sand and Gravel	Cement	Natur'l Mixture of Sand and Gravel			
			Bags	Cu. Ft.	Cu. Ft.		Gallons
1:2:4	1	4	2	7½	8½	2′ x 4′ x 11½″	10
1:3:6	1	6	2	11½	12	3′ x 4′ x 11½″	13½

much sand or finer material. Then, simply turning to Table XII, we look for 1:2:4 under the heading "Mixture." Reading across toward the right, we find under the heading "Quantities of Material Required," that we shall have to measure out 7½ cubic feet of the natural mixture of sand and gravel for every 2 bags of cement used. The next column shows that every such batch will give us 8½ cubic feet of concrete; and under "Size of Measuring Boxes" we learn that the mixed sand and gravel for a batch should just fill a box 2 feet wide, 4 feet long, and 11½ inches deep, inside dimensions. Ten gallons of water may be tried in mixing the

first batch, but the quantity may have to be increased. This will depend somewhat on the way the aggregate is graded, and the amount of fine material present.

Possibly we may have figured out the number of cubic feet of concrete that will be required on a job, and our cement will be in barrels instead of bags. In that case, Table XIII will be found useful, as it shows the quantities of cement and aggregates in one cubic foot of concrete of varying mixtures.

TABLE XIII
Ingredients in One Cubic Foot of Concrete

Mixture	Quantities of Materials		
	Cement	Sand	Stone or Gravel
1:2:4	.058 bbl.	.0163 cu. yd.	.0326 cu. yd.
1:3:6	.041 "	.0174 "	.0348 "

For example, suppose the work consists of a concrete silo requiring in all 935 cu. ft. of concrete, of which 750 cu. ft. is to be 1:2:4 concrete, and 185 cu. ft. is to be 1:3:6 concrete. Also enough sand and cement is needed to paint the silo inside and outside, in all 400 sq. yds. of surface, with a 1:1 mixture of sand and cement. One cu. ft. of 1:1 mortar will paint about 15 sq. yds. of surface, and requires 0.1856 barrel of cement and 0.0263 cu. yd. of sand. Then we have:

Cement—

750 cu. ft. of 1 :2 :4 concrete is 750×.058 =43.5 bbls.
185 cu. ft. of 1 :3 :6 concrete is 185×.041 = 7.6 "
Painting is $\frac{400}{15}$×.1856= 4.9 "

Total cement .....56.0 bbls.

Sand—

750 cu. ft. of 1 :2 :4 concrete is 750×.0163=12.25 cu. yds.
185 cu. ft. of 1 :3 :6 concrete is 185×.0174= 3.25 " "
Painting is $\frac{400}{15}$×.0263= .75 " "

Total sand .....16.25 cu. yds.

Stone or Gravel—

750 cu. ft. of 1 :2 :4 concrete is 750×.0326=24.5 cu. yds.
185 cu. ft. of 1 :3 :6 concrete is 185×.0348= 6.5 " "

Total stone or gravel.....31.0 cu. yds.

Thus the necessary quantities of materials are: 56 bbls. of Portland cement; 16¼ cu. yds. of sand; 31 cu. yds. of stone or gravel.

It is always wise to order two or three extra barrels of cement, if the dealer is at considerable distance, as this avoids any possible trouble that a shortage might cause. Besides, any cement left over always comes in handy for repair work around the house or barn.

TABLE XIV

Materials for One Cubic Yard of Concrete

Proportions	Bbls. Cement	Bbls. Sand	Bbls. Gravel or Stone
1:2:4	1.57	3.14	6.28
1:2.5:5	1.29	3.23	6.45
1:3:6	1.10	3.30	6.60
1:4:8	0.85	3.40	6.80

Quantities per Cubic Yard. Any table giving the quantities to be used in mixing concrete by the cubic yard, can be only approximate. Varying fineness in the sand, or varying compactness in the concrete due to ramming, may

TABLE XV

Amount of Material Required for One Cubic Yard Rammed Concrete of Varying Mixture

Mixture			Stone, 1-inch and under, dust screened out			Stone, 2½-inch and under, dust screened out			Stone, 2½-inch, with most small stone screened out			Gravel, ¾-inch and under		
			Cement, Bbls.	Sand, cu. yds.	Stone, cu. yds.	Cement, Bbls.	Sand, cu. yds.	Stone, cu. yds.	Cement, Bbls.	Sand, cu. yds.	Stone, cu. yds.	Cement, Bbls.	Sand, cu. yds.	Gravel, cu. yds.
1	1.0	2.0	2.57	0.39	0.78	2.63	0.40	0.80	2.72	0.41	0.83	2.30	0.35	0.74
1	1.0	2.5	2.29	0.35	0.70	2.34	0.36	0.89	2.41	0.37	0.92	2.10	0.32	0.80
1	1.0	3.0	2.06	0.31	0.94	2.10	0.32	0.96	2.16	0.33	0.98	1.89	0.29	0.86
1	1.0	3.5	1.84	0.28	0.98	1.88	0.29	1.00	1.88	0.29	1.05	1.71	0.26	0.91
1	1.5	2.5	2.05	0.47	0.78	2.09	0.48	0.80	2.16	0.49	0.82	1.83	0.42	0.73
1	1.5	3.0	1.85	0.42	0.84	1.90	0.43	0.87	1.96	0.45	0.89	1.71	0.39	0.78
1	1.5	3.5	1.72	0.39	0.91	1.74	0.40	0.93	1.79	0.41	0.96	1.57	0.36	0.83
1	1.5	4.0	1.57	0.36	0.96	1.61	0.37	0.98	1.64	0.38	1.00	1.46	0.33	0.88
1	1.5	4.5	1.43	0.33	0.98	1.46	0.33	1.00	1.51	0.35	1.06	1.34	0.31	0.91
1	2.0	3.0	1.70	0.52	0.77	1.73	0.53	0.79	1.78	0.54	0.81	1.54	0.47	0.73
1	2.0	3.5	1.57	0.48	0.83	1.61	0.49	0.85	1.66	0.50	0.88	1.44	0.44	0.77
1	2.0	4.0	1.46	0.44	0.89	1.48	0.45	0.90	1.53	0.47	0.93	1.34	0.41	0.81
1	2.0	4.5	1.36	0.42	0.93	1.38	0.42	0.95	1.43	0.43	0.98	1.26	0.38	0.86
1	2.0	5.0	1.27	0.39	0.97	1.29	0.39	0.98	1.33	0.39	1.03	1.17	0.36	0.89
1	2.5	3.5	1.45	0.55	0.77	1.48	0.56	0.79	1.51	0.58	0.81	1.32	0.50	0.70
1	2.5	4.0	1.35	0.52	0.82	1.38	0.53	0.84	1.42	0.54	0.87	1.24	0.47	0.75
1	2.5	4.5	1.27	0.48	0.87	1.29	0.49	0.88	1.33	0.51	0.91	1.16	0.44	0.80
1	2.5	5.0	1.19	0.46	0 91	1.21	0.46	0.92	1.26	0.48	0.96	1.10	0.42	0.83
1	2.5	5.5	1.13	0.43	0.94	1.15	0.44	0.96	1.18	0.44	0.99	1.03	0.39	0.86
1	2.5	6.0	1.07	0.41	0.97	1.07	0.41	0.98	1.10	0.41	1.03	0.98	0.37	0.89
1	3.0	4.0	1.26	0.58	0.77	1.28	0.58	0.78	1.32	0.60	0.80	1.15	0.52	0.72
1	3.0	4.5	1.18	0.54	0.81	1.20	0.55	0.82	1.24	0.57	0.85	1.09	0.50	0.75
1	3.0	5.0	1.11	0.51	0.85	1.14	0.52	0.87	1.17	0.54	0.89	1.03	0.47	0.78
1	3.0	5.5	1.06	0.48	0.89	1.07	0.49	0.90	1.11	0.51	0.93	0.97	0.44	0.81
1	3.0	6.0	1.01	0.46	0.92	1.02	0.47	0.93	1.06	0.48	0.97	0.92	0.42	0.84
1	3.0	6.5	0.96	0.44	0.95	0.98	0.44	0.96	1.00	0.45	1.01	0.88	0.40	0.87
1	3.0	7.0	0.91	0.42	0.97	0.92	0.42	0.98	0.94	0.42	1.05	0.84	0.38	0.89
1	3.5	5.0	1.05	0.56	0.80	1.07	0.57	0.82	1.11	0.59	0.85	0.96	0.50	0.76
1	3.5	5.5	1.00	0.53	0.84	1.02	0.54	0.85	1.06	0.56	0.89	0.92	0.48	0.78
1	3.5	6.0	0.95	0.50	0.87	0.97	0.51	0.89	1.00	0.53	0.92	0.88	0.46	0.80
1	3.5	6.5	0.92	0.49	0.91	0.93	0.49	0.92	0.96	0.51	0.95	0.83	0.44	0.82
1	3.5	7.0	0.87	0.47	0.93	0.89	0.47	0.95	0.91	0.49	0.98	0.80	0.43	0.85
1	3.5	7.5	0.84	0.45	0.96	0.86	0.45	0.98	0.86	0.47	1.01	0.76	0.41	0.87
1	3.5	8.0	0.80	0.42	0.97	0.82	0.43	1.01	0.81	0.45	1.04	0.73	0.39	0.89
1	4.0	6.0	0.90	0.55	0.82	0.92	0.56	0.84	0.95	0.58	0.87	0.83	0.51	0.77
1	4.0	6.5	0.87	0.53	0.85	0.88	0.53	0.87	0.91	0.55	0.90	0.80	0.49	0.79
1	4.0	7.0	0.83	0.51	0.89	0.84	0.51	0.90	0.87	0.53	0.93	0.77	0.47	0.81
1	4.0	7.5	0.80	0.49	0.91	0.81	0.50	0.93	0.84	0.51	0.96	0.73	0.44	0.83
1	4.0	8.0	0.77	0.47	0.93	0.78	0.48	0.95	0.81	0.49	0.98	0.71	0.43	0.86
1	4.0	8.5	0.74	0.45	0.95	0.76	0.46	0.98	0.78	0.47	1.01	0.68	0.42	0.88
1	4.0	9.0	0.71	0.43	0.97	0.73	0.44	1.01	0.75	0.45	1.04	0.65	0.40	0.89
1	5.0	9.0	0.66	0.50	0.90	0.67	0.52	0.93	0.70	0.53	0.96	0.61	0.46	0.83
1	5.0	10.0	0.62	0.47	0.95	0.63	0.48	0.96	0.65	0.50	1.00	0.57	0.43	0.87

affect the quantities by 10 per cent in any direction.

Table XIV, showing the number of barrels of cement, sand, and gravel required for one cubic yard of concrete of different mixtures, will therefore serve a useful purpose only for estimating roughly the quantities and cost of materials.

A more nearly accurate determination can be made by referring to Table XV, which indicates the number of barrels of Portland cement, and the fraction of a cubic yard of both sand and stone, required for making one cubic yard of rammed concrete of variously proportioned mixtures with different coarse aggregates.

Measuring According to Voids. As an approximate guide to the use of Table XV and other tables, **where a determination of voids has been made,** it may be pointed out that 45 per cent voids in the coarse aggregate would indicate the average conditions, and would be about what is found in broken stone with dust screened out; 40 per cent voids would correspond to gravel or mixed stone and gravel; 50 per cent voids would indicate poor grading, as in an aggregate screened to uniform size; while 30 per cent voids and under would indicate an aggregate graded with great care.

Where voids have been determined in both sand and coarse aggregate, the upper part of Table XVI, which may be taken as representing average conditions, will be found useful.

TABLE XVI

Ingredients in One Cubic Yard of Concrete

(H. P. Gillette)

Sand voids 40%. Stone voids 45%. Barrel of Portland Cement containing 3.65 cu. ft. of paste. Barrel specified 3.8 cu. ft.

Proportions by Volume	1:2:4	1:2:5	1:2:6	1:2.5:5	1:2.5:6	1:3:4
Bbls. cement per cu. yd. concrete.....	1.46	1.30	1.18	1.13	1.00	1.25
Cu. yds. sand " " " "	0.41	0.36	0.33	0.40	0.35	0.53
Cu. yds. stone " " " "	0.82	0.90	1.00	0.80	0.84	0.71
Proportions by Volume	**1:3:5**	**1:3:6**	**1:3:7**	**1:4:7**	**1:4:8**	**1:4:9**
Bbls. cement per cu. yd. concrete.....	1.13	1.05	0.96	0.82	0.77	0.73
Cu. yds. sand " " " "	0.48	0.44	0.40	0.45	0.43	0.41
Cu. yds. stone " " " "	0.80	0.88	0.93	0.80	0.86	0.92

Where the voids are the same as in the upper part of Table XVI, but the cement is measured loose in a box after dumping from a barrel, the quantities should be determined from the lower part of the table, as under such conditions a barrel of cement yields 4.4 cu. ft. of loose cement:

Proportions by Volume	1:2:4	1:2:5	1:2:6	1:2.5:5	1:2.5:6	1:3:4
Bbls. cement per cu. yd. concrete.....	1.30	1.16	1.00	1.07	0.96	1.08
Cu. yds. sand " " " "	0.42	0.38	0.33	0.44	0.40	0.53
Cu. yds. stone " " " "	0.84	0.95	1.00	0.88	0.95	0.71
Proportions by Volume	**1:3:5**	**1:3:6**	**1:3:7**	**1:4:7**	**1:4:8**	**1:4:9**
Bbls. cement per cu. yd. concrete.....	0.96	0.90	0.82	0.75	0.68	0.64
Cu. yds. sand " " " "	0.47	0.44	0.40	0.49	0.44	0.42
Cu. yds. stone " " " "	0.78	0.88	0.93	0.86	0.88	0.95

From the above table it will be seen that the following rule can be deduced: Add together the number of parts, and divide this sum into 10;

the quotient will be approximately the number of barrels per cubic yard. Thus, for 1:2:5 concrete, the sum of the parts is 8, and 10÷8=1.25 barrels of cement per yard, which is approximately equal to 1.30, the amount called for by the table.

MIXING OF CONCRETE

The methods of mixing concrete vary greatly in detail, but may be broadly divided under two heads—**mixing by hand** and **mixing by machinery.** A further distinction is made among mixing processes, which may be either **batch mixing** or **continuous mixing.** Batch mixing, as the name implies, is an intermittent process, the ingredients being measured out, and the mixing done for only a "batch" or limited, definite quantity at one time. Continuous mixing is always done by machinery, the materials being fed to the machine in an uninterrupted stream, continuously during the entire mixing process. Batch mixing may be done either by hand or by machine. In machine mixing, both continuous and batch, the proportioning of ingredients is sometimes done automatically by the machine itself.

Hand Mixing vs. Machine Mixing. A choice as between hand mixing and machine mixing will depend chiefly on considerations of cost. Both methods will produce equally good concrete **if sufficient care is taken to insure a thorough and uniform mixture.** This is harder to

make sure of with hand than with machine mixing, for, with the increasing fatigue of a day's work, and possibly that carelessness of workmanship which is bred of familiarity and monotony, a workman will naturally and inevitably show some falling-off in sharpness of attention and thoroughness of work toward the close of the day. Therefore, even with the closest supervision kept up by a good foreman, hand-mixed concrete is likely to be not quite so strong or so uniform in quality as the machine-mixed product—and this may be the case without any intentional neglect on the part of workmen.

Under any method of mixing—hand or machine—a careful and constant watch should be kept upon every detail of the process, to see that the proper relative quantities of the dry ingredients are being used, that the mixing is being thoroughly done, and that the concrete is of the proper consistency or degree of wetness. The same careful supervision should be kept up over every detail of the subsequent depositing, ramming, spading, drying, etc., of the concrete.

On small jobs—even those requiring as much as several hundred cubic yards of concrete—it is ordinarily much cheaper and more expedient to mix by hand. This is, of course, especially true where only a small crew—say two to four men—are available for the mixing, and where the work is often interrupted or frequent moving is necessary.

On large jobs it is more economical to mix by

machinery, and this is the method generally adopted. The economy of machine mixing, on large jobs, depends to some extent on the use of labor-saving appliances in handling the raw materials and the finished mixture. Wheelbarrow work in delivering materials to the mixer and carrying away the concrete to where it is deposited, will make the cost relatively high in any case, which will be greatly reduced if the mixer can be fed by gravity from bins, and the concrete dumped into hauling cars. On small jobs, however, the saving in hand labor is usually more than offset by the cost of the mixing plant and its maintenance and operation. The relative cost of the two methods usually depends on local circumstances, and these must be taken into consideration in each particular case.

Tests made by United States government engineers at Duluth, Minn., to determine the relative strength of concrete mixed by hand and by a batch mixer, showed that at 7 days hand-mixed concrete possessed only 53 per cent of the strength of machine-mixed concrete; at 28 days, 77 per cent; at 6 months, 84 per cent; and at one year, 88 per cent. There was also less uniformity of strength in the hand-mixed concrete.

Mixing Concrete by Hand

Details of the mixing process differ considerably among different workers, one preferring one method, another another. Usually the sand

and cement are mixed first, dry, and afterward mixed with the stone before the water is added. Sometimes the cement and sand are first mixed into a mortar, before being mixed with the stone. The stone may be added to the dry cement and sand, or to the mortar, or vice versa. Sometimes the stone, sand, and cement are spread in successive layers, slightly mixed, and shoveled up into the form of a crater, into which water is poured, and the mass turned with shovels.

The essential thing in all cases is to see that the mass is turned a sufficient number of times to insure a thorough mixture.

The following account of the mixing of a small batch of concrete—condensed from a description given by Messrs. Wilson and Gaylord—will serve as a general illustration of details of procedure in ordinary practice on small jobs. The mixture is a 2-bag batch of 1:2:4 concrete, and two men are sufficient for the work.

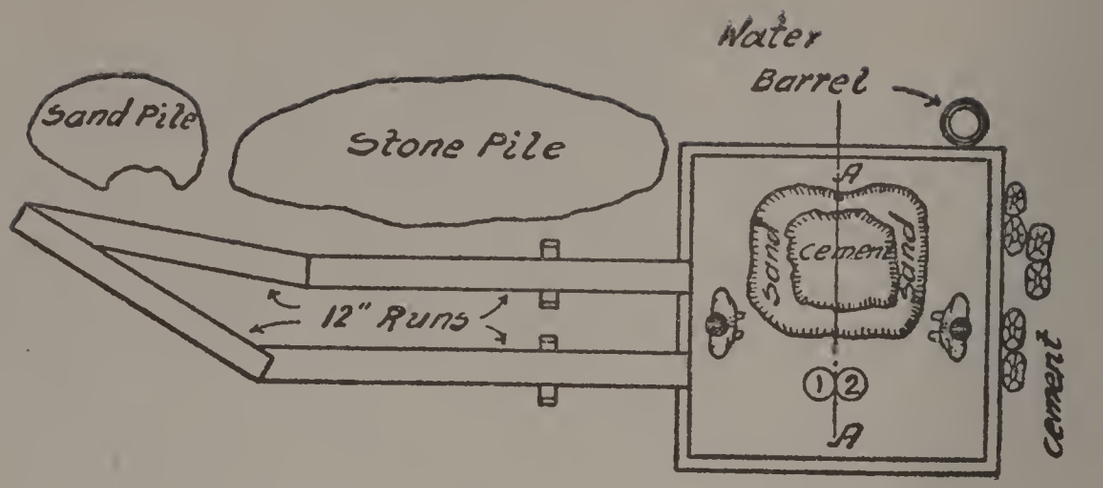
The Concreting Plant. The batch will be mixed on a wooden platform known as a **concrete board.** For two men, this should be 9 feet by 10 feet for a 2-bag batch, or 12 by 10 feet for a 4-bag batch. Make it out of 1-inch boards, 10 feet long, surfaced on one side, using five 2 by 4-inch by 9-foot cleats to hold them together. The boards are so laid as to enable the shoveling to be done with, and not against, the cracks between the boards. The boards must be drawn up close in nailing, so that no cement grout will run through while mixing. If tongued-and-

grooved boards are available, so much the better. Knot-holes may be closed by nailing a strip across them on the under side of the board. It is a good precaution against losing cement grout, to nail a 2 by 2-inch or 2 by 4-inch piece around the outer edge of the board. Often 2-inch planks are used in making concrete boards, but these are unnecessarily heavy, and very cumbersome to move (see Plate 3).

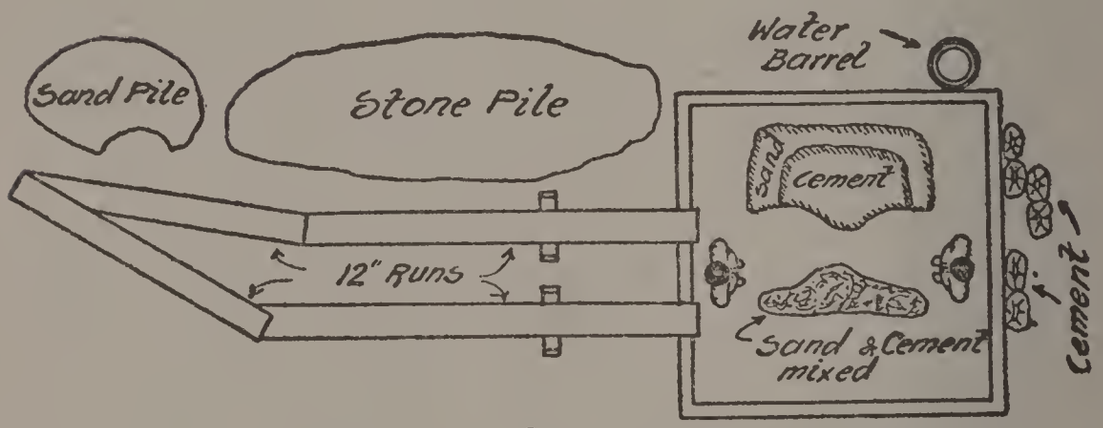
The concrete board is usually best placed as close as possible to the forms in which the concrete is to be deposited, but local conditions must govern this point. Choose a place giving plenty of room, near the storage piles of sand and stone (or gravel). Block up your concrete board level, so that the cement grout will not run off on one side, and so that the board will not sag in the middle under the weight of the concrete.

Make the runways for the wheelbarrows of good, strong plank 2 to 3 inches thick and 10 to 12 inches wide. They should be of liberal width —say at least 20 inches wide if lifted much above the ground—as this feature will help greatly to lighten and quicken the work.

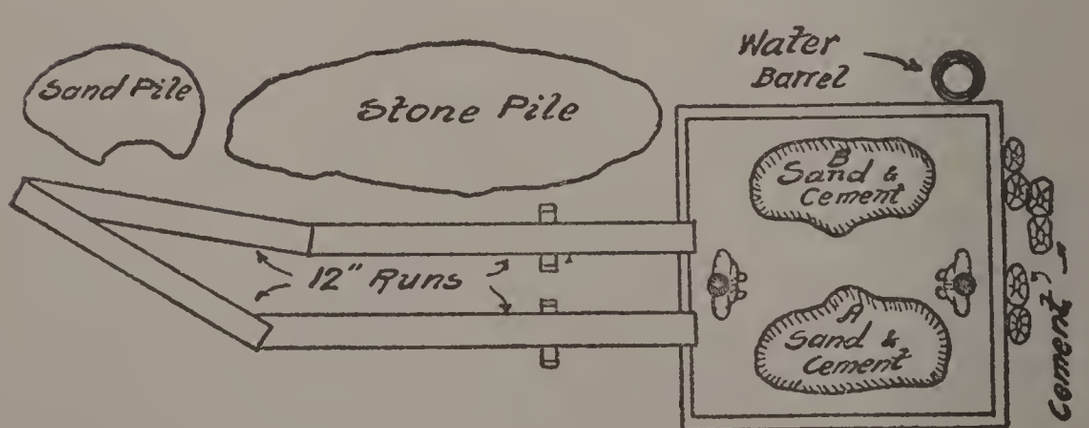
In addition to board and runs as described above, the concreting outfit will include the following tools: **Shovels,** No. 3, square point; **wheelbarrows,** at least two being necessary for quick work (sheet-iron body preferred); **rake; water barrel; water buckets,** 2-gallon size; **tamper,** 4 by 4 inches by 2 feet 6 inches, with handles



a
Spreading Cement over Sand



b
First Turning, Sand and Cement



c
Second Turning, Sand and Cement

Fig. 10. Illustrating Hand-Mixing of Concrete.

nailed to it, as shown in Plate 3; **garden spade,** or **spading tool** cut from a board and beveled to a thin edge at the bottom, as shown in the hands of the man on the concrete board, Plate 3, or in Fig. 12; and a **sand screen,** made by nailing a piece of ¼-inch-mesh wire screen 2½ ft. by 5 ft. in size to a frame made of 2-in. by 4-in. stuff.

Mixing. With the mixing board placed and the "runs" made, the concrete plant is ready.

First load your sand in wheelbarrows from the sand pile, wheel onto the board, and fill the sand-measuring box, which is placed about two feet from one of the 10-foot sides of the board. When the sand box is filled, lift it off, and spread the sand over the board in a layer 3 or 4 inches thick, as shown in Fig. 10 (a). Take the two bags of cement, and place the contents as evenly as possible over the sand (a, Fig. 10). With the two men standing at points indicated, start mixing the sand and cement, each man turning over the half on his side of the line A-A. Starting at his feet and pushing the shovel away from him, each man takes a full shovel-load, and turns the shovel over at the points marked 1 and 2. In turning the shovel, do not simply dump the sand and cement at the points marked 1 and 2 in the diagram, but shake the materials off the end and sides of the shovel, so that the sand and cement are mixed as they fall. This is a great assistance in mixing these materials. In this way the material is shoveled from one side of the board to the other, as shown in Fig. 10 (b and c). Fig.

10 (b) shows the first turning; and Fig. 10 (c), the second turning.

The sand and cement should now be well mixed and ready for the stone and water. After the last turning, spread the sand and cement out carefully; place the gravel or stone measuring box beside it as shown in Fig. 11 (a); and fill from the gravel pile. Lift off the box, and shovel the gravel on top of the sand and cement, spreading it as evenly as possible. With some experience, equally good results can be obtained by placing the gravel measuring box on top of the carefully leveled sand and cement mixture, and filling it, thus placing the gravel on top without an extra shoveling. This method is shown in Fig. 11 (b).

Now add about three-fourths the required amount of water, using a bucket, and dashing the water over the gravel on top of the pile as evenly as possible. Be careful not to let too much water get near the edges of the pile, as it will run off, taking some cement with it. This caution, however, does not apply to a properly constructed mixing board, as the cement and water cannot get away.

Starting the same as with the sand and cement, turn the materials over in much the same way, except that, instead of shaking the materials off the end of the shovel, the whole shovelload is dumped as at points 1 or 2 (a, Fig. 10), and dragged back toward the mixer with the square point of the shovel. This mixes the

Courtesy of Association of American Portland Cement Manufacturers.

A COMPLETE CONCRETE HAND-MIXING PLANT FOR SMALL BATCH WORK.

Showing concrete board, outfit of tools, etc.

ARTISTIC ADAPTATION OF CONCRETE BLOCKS TO HOUSE CONSTRUCTION.
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Awnings add to attractive appearance.

gravel with the sand and cement, the wet gravel picking up the sand and cement as it rolls over when dragged back by the shovel. Add water to the dry spots as the mixing goes on, until all the required water has been used. Turn the mass back again, as was done with the sand and cement.

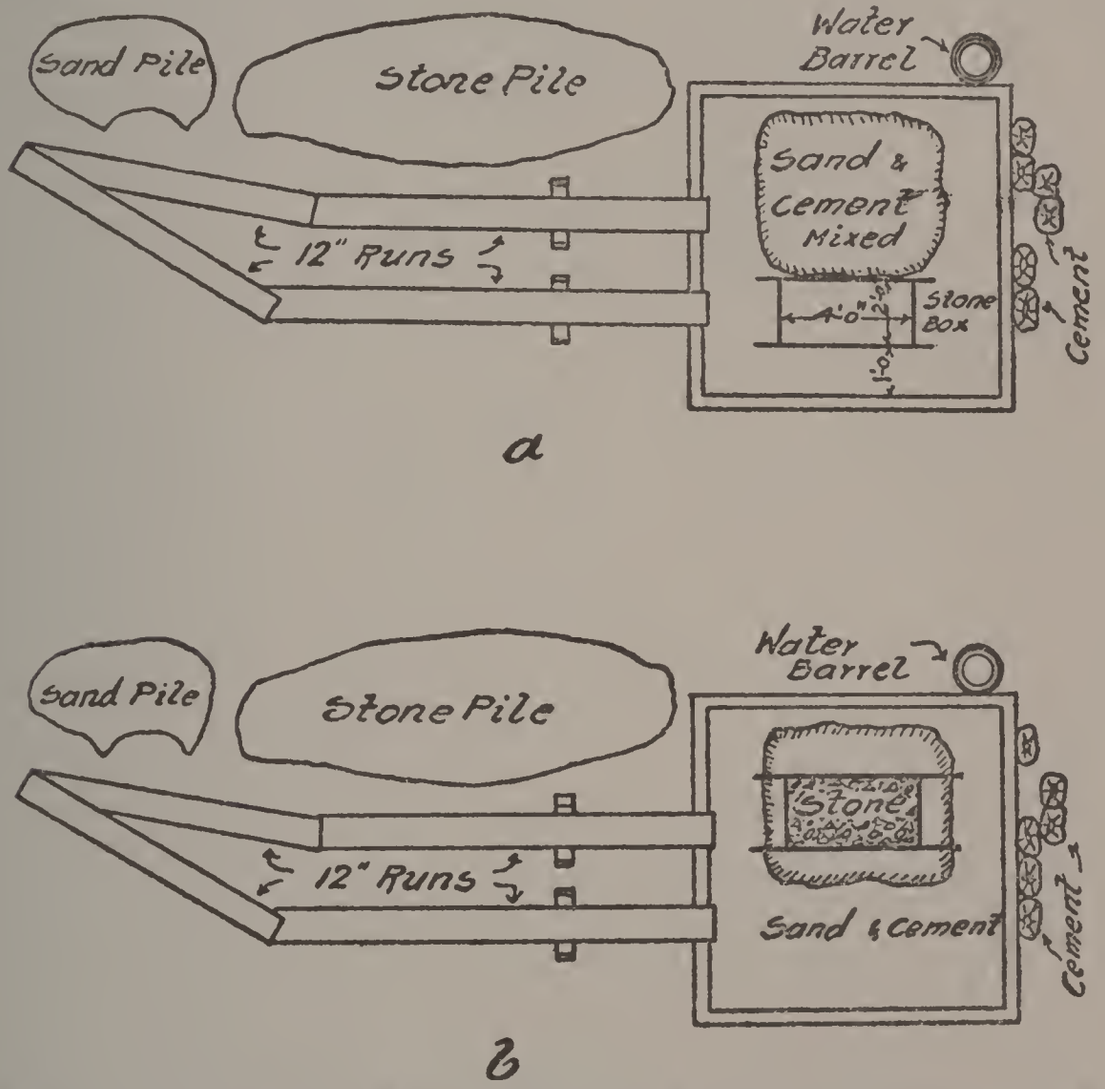


Fig. 11. Illustrating Two Methods of Adding the Coarse Aggregates in Mixing Concrete.

With experienced laborers, the concrete would be well mixed after three such turnings; but if it shows streaky or dry spots, it must be turned again. After the final turning, shovel

into a compact pile. The concrete is now ready for placing.

When the sand and gravel are found already mixed, as in a natural bank, spread out the mixture of sand and gravel as much as the board will readily permit; add enough water to wet the gravel and sand thoroughly; spread the cement evenly in a thin layer over the sand and gravel; and turn over, as described previously, at least three times, adding the rest of the water necessary to get the required consistency while the materials are being turned. It requires some experience to work up a natural mixture of bank sand and gravel; and, if at all doubtful about the concrete made from it, first screen the sand from the gravel, and then mix in the regular way.

Number of Men. For the above operation, only two men are required, although more can be used to advantage. If three men are available, let two of them mix as described above, and let the third man supply the water, help mix the concrete by raking over the dry or unmixed spots as the two mixers turn the concrete, help load the wheelbarrows with sand and stone or gravel, etc.

If four men are available, it is best to increase the size of the batch mixed to a four-bag batch, doubling the quantities of all materials used. The cement board should also be increased to 10 feet by 12 feet. In this case, start the mixing in the middle of the board, each pair of men mixing exactly as if for a two-bag batch, except

that the concrete is shoveled into one big mass each time it is turned back onto the center of the board.

When more than four men are available, the rest may place the concrete, make new runs, load wheelbarrows, etc., taking the concrete away from the board as fast as it is mixed. In this case, another small concrete board should be placed next to the big board, so that in the last turning the batch can be shoveled over onto the small board for placing, making room on the big board to mix the next batch. The small platform need be only just big enough to hold the pile of mixed concrete.

Measuring by Wheelbarrow. With a little practice, the sand and stone or gravel can be measured by the number of wheelbarrow loads almost as accurately as by means of the measuring boxes.

If the concrete has to be wheeled not over 50 feet, four experienced men should be able, on an average, to mix and wheel to the place of deposit about 10 four-bag batches of 1:3:6 concrete in 10 hours. And since, from Table XII, one 4-bag batch will make 24 cubic feet of concrete, the four men should mix and wheel in this period of time about 240 cubic feet of concrete, or $240 \div 27 = 8.8$ cubic yards. This estimate, however, is for the very simplest kind of concreting, and makes no allowance for the labor of supplying materials to the mixing platform or for building forms.

Mixing by Machinery. The details of machine mixing will be taken up later in connection with the description of the various types of concrete mixers, under the head of "Concreting Machinery and Tools."

To Regulate Setting and Hardening. As already explained, some regulation of the time of setting of cement can be accomplished by regulating the consistency of the mixture, a dry mixture setting more quickly than a wet one. Also, since concrete sets more rapidly in warm than cold weather, the setting may be regulated to some extent by simulating the proper weather conditions. This may be done by constructing a light framework over the job, covering it with canvas or other material, and regulating the temperature within by means of stoves. This method, however, is very expensive, and is used only in building construction, being employed then chiefly as a protection to the concrete during the setting process in freezing weather.

When it is desired to obtain a very rapid setting and hardening, as in making casts and ornamental forms, a 10 per cent solution of **calcium chloride** may be used instead of water, for mixing and pouring. This material is cheap, and can be obtained from any dealer in chemicals, or in large quantities from manufacturing chemists. A 10 per cent solution is obtained by dissolving 8 pounds of calcium chloride in 10 gallons of water. Artificial stone made in this way will harden, and can be removed from moulds or

forms, in one-third the time required when only water is used for mixing. The chemical is said to have no injurious effect whatever on the strength or soundness of the cement.

DEPOSITING CONCRETE

Concrete should not be allowed to stand unused for any considerable length of time after being mixed, but should be placed or deposited **at once.** In no case should this be delayed beyond 20 to 30 minutes after the cement is first wet.

Effect of Remixing. To disturb the concrete after it has begun to set, will not only retard its setting, but may possibly prevent the development of its full, ultimate strength. This is particularly true where the cement is to be used in reinforced work, as remixing reduces the adhesiveness and binding power of the cement. If it is permissible to wait a long time—say several months—for the development of the full strength of the concrete, remixing of both Portland and natural cement mortar and concrete might be allowed, if done shortly after initial set has begun—say within an hour or two; but if, as is usually the case, it is desirable that the mixture shall acquire its full strength within a few days or weeks, then cement mortar or concrete which has begun to set before placing should be rejected.

If the mixing process is kept up for about

two hours continuously before placing, it has been found that the strength of the mixture will be considerably increased, this being due, in all probability, to the more thorough blending and interpenetration of the constituents of the mortar or concrete.

Concrete is usually deposited in layers 4 to 12 inches thick. Unless otherwise specified, it should be placed in layers of about 6 inches.

Method of Placing. In the placing of concrete, the most important thing is to **handle it in such a way that its materials will not be separated.** The mass should retain its compactness and its even distribution of ingredients; the stone or gravel should never become separated from the mortar. Provided this precaution is taken, concrete may be handled and placed in any manner suited to the nature of the work. It may be shoveled off the mixing board directly into the trench or forms; shoveled into wheelbarrows, wheeled to place, and dumped; shoveled into cars or carts, and hauled to the work; shoveled or dumped down an inclined chute; shoveled into buckets or hods and lifted or carried to place, etc.

If dumped into a trench or form from any considerable height, the work should be watched with special care to see that the heavier particles are not forced toward the bottom of the mass, and that the stone or gravel still remains in intimate contact with the mortar. Where depositing from a considerable height is necessary,

a chute should invariably be used if the mixture is a "dry" one. A very wet mixture, however, is much easier to handle in such a case than a dry mixture, and the stone or gravel will not so readily be separated from the mortar.

Ramming or Tamping Concrete. In order to force out air-bubbles and obtain a thoroughly compact job, concrete should be rammed (or tamped) immediately after placing. The amount of ramming needed depends on the consistency of the mixture. If very wet, only the slightest tamping, if any, is necessary—merely enough to level off across the top. If much tamping is done to a very wet mixture, the particles of the coarse aggregate may be forced together in one part of the mass, and their uniform distribution be upset. Sometimes a very wet mixture, instead of being tamped, is simply **puddled** (stirred up), this being done with a piece of reinforcing bar or other convenient material.

A medium wet mixture should be tamped until thoroughly compacted, when it will quake like jelly.

A dry mixture must be very thoroughly tamped—until the water is forced to the surface.

The tamper for medium or dry concrete may consist of a steel shoe or plate with a face about 6 inches square, to the back of which a handle of convenient length is fastened; or, for small work, a satisfactory home-made tamper may be

constructed from a cylindrical block of wood into one end of which a handle is fastened. For work in very thin sections or between reinforcing steel members, a suitable rammer can be made from board 1 inch or so in thickness, the blade left at the lower end being about 8 inches high by 3 inches wide.

Spading. In order to insure a smooth, unbroken face on the concrete, it should be carefully **spaded** next to the forms, where the finished concrete will be exposed to view. And this is true whether the mixture be dry, medium, or very wet. The operation of spading consists in running a spade or flattened shovel down against the face of the form, and working up and down. This action causes the stone or gravel to be pushed back slightly from the form, and allows the cement grout to flow against the face of the form and fill any voids that may be there, thus making the face of the work present an even, homogeneous appearance. Where the narrowness of the concrete section, such as in a 6-inch silo wall, prevents the use of a spade, a 1-inch by 4-inch board, sharpened to chisel edge on the end, will do as well. Only sharpen on one side, and place the flat side against the form, as shown in Fig. 12. In the case of a dry mixture, spading must be done with greatest care by experienced hands, to get uniform results; but with a medium or very wet mixture, it is very easy to obtain first-class work; indeed, with a wet mixture, spading

is required only as an added precaution against the possibility of voids in the face of the work, and is really necessary in few cases.

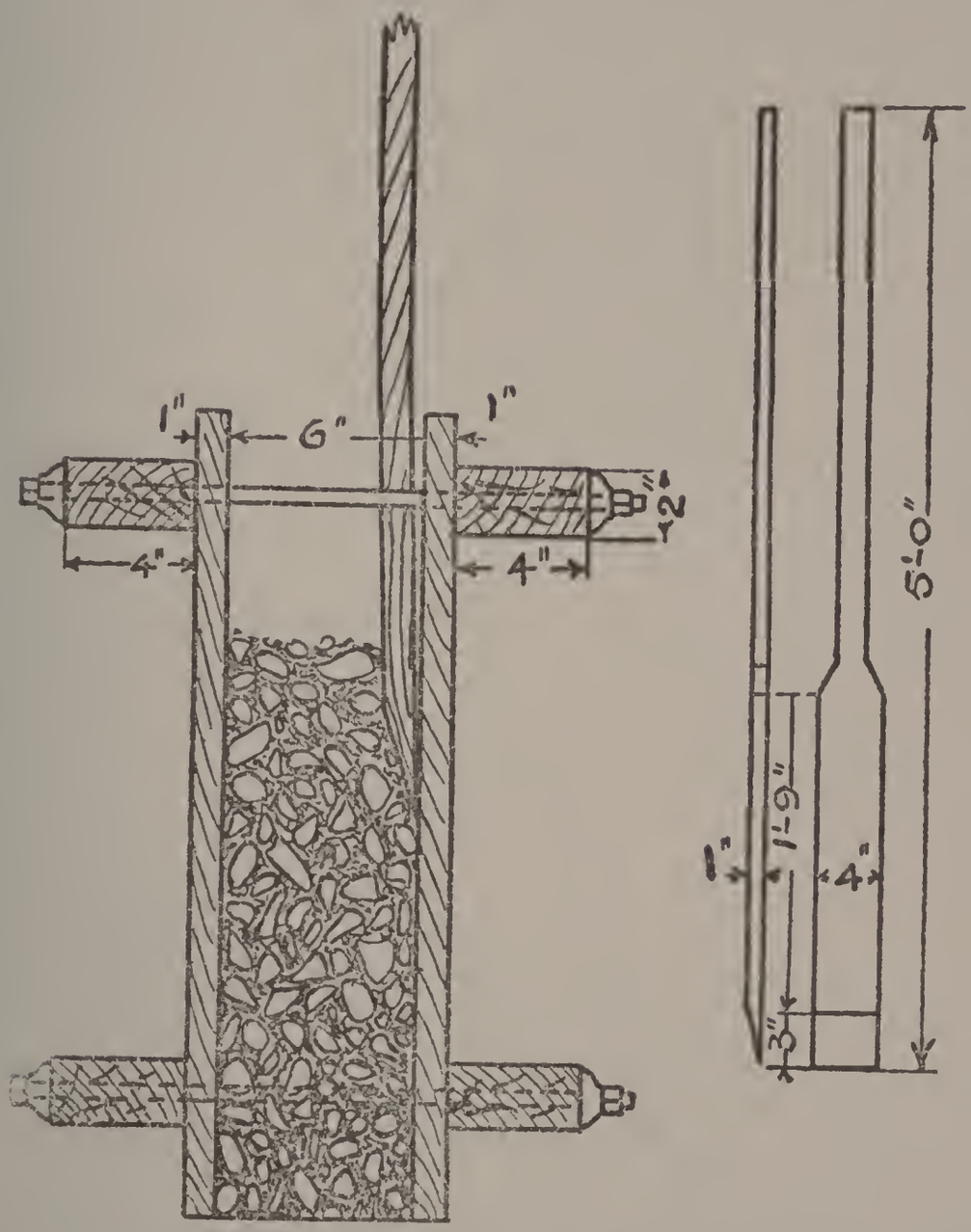


Fig. 12. **Diagram Showing Method of Spading a 6-Inch Concrete Wall.**
At right is a diagram giving details of wooden spading tool.

In spading, be careful not to pry with the spade, as this may spring the forms.

Protection of Concrete after Placing. Green concrete should not be exposed to the sun until

after it has been allowed to set for five or six days. Each day during that period the concrete should be wet down by sprinkling water on it, both in the morning and afternoon. This is done so that the concrete on the outside will not dry out much faster than the concrete in the center of the mass; and it should be carried out carefully, especially during the hot summer months. Old canvas, sheeting, burlap, etc., placed so as to hang an inch or so away from the face of the concrete, will do very well as a protection. Wet this as well as the concrete. Often the concrete forms can be left in place a week or ten days; this protects the concrete during the setting-up period, and the above precautions are then unnecessary.

Cleaning the Concrete Board. When the day's work is done, carefully clean all the tools, especially the concrete board. Remove with a shovel all the loose cement, sand, and stone. Then scrub the board with a broom and water. If this is not done, small particles of stone are glued to the board by the cement, and render shoveling the next day most difficult.

Bonding Old and New Concrete. Considerable care is necessary in order to secure a perfect bond or joint when new concrete is to be connected to old, or when a job of concreting interrupted for a considerable time is resumed, as when workmen quit work one day to take it up again the following day.

In ordinary work subject chiefly to com-

pressive strains, as in foundations, it will be sufficient if the surface of the concrete laid one day is merely washed with clean water before laying on the new concrete the next day; but in walls and floors, or where tensile stresses will be developed, the surface to be joined should be thoroughly washed clean and soaked with water, and then painted either with neat cement (cement and water) or with a very thin, rich mortar consisting of 1 part cement to 1 part sand. If the old surface is very dirty, it may be necessary, after washing it as clean as possible, to pick it with a cold chisel in order to expose a perfectly clean and somewhat rough surface of concrete.

It will always help in the subsequent securing of a good bond with later work, if the old surface, after ramming or troweling, is scratched or roughened.

Where a water-tight wall is desired, as in a tank, if the concrete is laid in successive tiers and not by one continuous operation, special joints should be made which will give a mechanical as well as a chemical bond. They may be square or V-shaped in section, and either horizontal or vertical. Such joints are moulded by placing pieces of timber so that they will form grooves in the surface of the concrete when the last layer is placed each day, then removing the wood the following day, and coating the joint with neat cement or very thin, rich mortar before placing the next layer of concrete.

Concreting in Frosty Weather

After concrete has once firmly set and hardened, frost has no effect upon it. It is different, however, if frost is allowed to attack the concrete while being mixed or placed, or during the setting process.

Many special tests and many investigations of work in progress have been made, in order to determine the effect of freezing upon Portland cement concrete before it has had a chance to set. While some difference of opinion on this subject exists, it is the generally accepted conclusion of engineers that freezing does not materially affect the binding quality of good Portland cement, and that concrete laid in freezing weather will not be injured provided it does not freeze till after placing, and provided also that it is not subjected to any load until after it has been thawed out and allowed to set in the usual way. The freezing simply retards the process of hardening, which will again proceed under favorable conditions, until the concrete eventually develops its full strength.

On the other hand, alternate freezing and thawing before hardening is complete, is very apt to injure concrete. Accordingly, if concrete has once been frozen and thawed out before the action of hardening has commenced, it should be protected from freezing again until it has had a chance to harden sufficiently to withstand the action of subsequent frosts.

The freezing of a layer of concrete is very apt to prevent a good bond with another layer placed on top. In sidewalk and pavement work, freezing during construction is apt to cause a thin layer (about $^1/_{12}$ inch in depth) to peel off, leaving the wearing surface rough; and a similar effect is sometimes seen on concrete walls. The injury, however, will not be deep-seated unless the whole mass has been subjected to repeated freezing and thawing before hardening is complete.

A green concrete mixture which can be easily frozen at a temperature below 32 degrees F. (the freezing point of water), should not be allowed to freeze, if this can be prevented. **It is safest, therefore, to avoid mixing and placing concrete in freezing weather.**

Sometimes, however, this has to be done, and the work has to be pushed forward irrespective of weather conditions. Fortunately, good results can be obtained with almost any degree of cold, by taking proper precautions; but these invariably add to the cost by entailing additional expenses.

The elaborateness of the precautions necessary to insure satisfactory results on a job of concreting done in freezing weather, will depend upon the class of construction and the importance of the work. Plain, massive work, for example, does not require the same degree of care and protection in frosty weather, as is necessary for small reinforced construction.

Protection from Frost. There are two general methods in use for protecting concrete from injury by frost, and expediting the progress of construction—namely, first, by using artificial heat; second, by using chemicals to lower the freezing point of the wet mixture so that the prevailing frost will not affect it. Sometimes both methods are employed on the same work.

Lowering the freezing point of the concrete is the simplest and cheapest, but probably not the best method of concreting in freezing weather. This method consists of adding some substance to the mixing water that will reduce its freezing point; but only those substances that have no effect on the strength and durability of the concrete can be used. **Ordinary salt** is most commonly used for this purpose; and experiments indicate that while the addition of a limited amount of salt retards the hardening somewhat, and lowers the initial strength, the ultimate strength of the concrete is not affected by its use. Salt should be used only in plain concrete work, as its effect on reinforcing metal has not been established. Even when salt is used, it is important that the aggregates be free from lumps of frozen material, as it is impossible properly to mix such materials. Approximately one per cent by weight of salt to the weight of the water is required for each degree Fahrenheit below freezing; but more than ten per cent of salt—which is equivalent to about 13 pounds of salt to a barrel of cement—should not be con-

sidered safe, and this amount is not effective for temperatures lower than 22 degrees Fahrenheit.

The use of artificial heat may be accomplished in different ways—by inclosing the entire work under cover, and keeping it warm by heating the air within the enclosure; or by heating the aggregates or water, or both, before mixing. The former is the most expensive method, and is never employed except in building construction. The inclosing framework is lightly constructed of wood, covered with canvas or other material.

The **best method** of concreting in freezing weather is to heat the materials, and to protect the work until it has obtained sufficient strength to withstand the action of frost. Either the water, the sand and water, or the sand, stone, and water should be heated. The cement is usually not heated. Heating the materials accelerates the rate of hardening; lengthens the time before the material becomes cold enough to freeze; and, in temperatures but little below freezing, will insure the hardening of the concrete before it can be damaged by frost.

For heavy mass work, thick walls, abutments, etc., it is not necessary to heat the stone except in unusually cold weather, but sand and water should be heated. If the forms are tight and made of heavy material, it will be necessary to protect only the top of the work; this may be done by covering with a canvas and running

steam under it, or by covering with boards or paper and applying a covering of straw or manure. In no case, however, should fresh manure be allowed to come in contact with very green concrete, as it will discolor and spoil the surface. If the work, covered in the manner described, is protected from freezing for several days, it is sufficient, unless it has to be loaded immediately; but thin walls, light foundations, etc., should be protected on all sides in the manner pointed out above. For reinforced work it is necessary to heat all the materials but the cement; and the concrete should be hot when placed in the forms. Where the work must be placed in service as soon as possible, the only safe practice is to keep the surrounding temperature well above the freezing point until the work has thoroughly hardened.

The aggregates may be heated by being piled over sheet-iron pipes or drums in which fires are built, or over steam pipes laid through the bottom of the storage bins. The water may be heated by exhaust steam or in any other convenient way. When a mechanical mixer is used, it also is sometimes kept warm, by means of steam coils outside and jets inside.

Concrete increases in strength but very slowly in cold weather; and for this reason, forms should be left on as long as possible, and care taken not to load a structure too soon. Just how old the work should be before removing the forms and subjecting it to its load, cannot be

CONCRETE HOUSE WITH OUTDOOR LIVING ROOM.

COZY LITTLE FIVE-ROOM CONCRETE BUNGALOW.

Walls and shrubbery give privacy.

A COMPACT LITTLE HOME, EASILY KEPT LOOKING TRIM AND NEAT.

Showing possibilities of cobblestone ornamentation.

CONCRETE BUNGALOW WITH TILE ROOF AND COBBLESTONE ORNAMENTATION.

stated, as this will depend entirely upon how fast the concrete hardens. Careful inspection of the structure is necessary before removing the forms and applying the load; and it must be remembered that frozen concrete closely resembles thoroughly hardened concrete in appearance, and, when broken, frequently shows a fracture through the aggregate, although upon thawing it may have but little strength.

General Working Rules

Working with concrete is not an occupation in which the layman can experiment inexpensively. The general rule may well be laid down: Do not purchase an ounce of cement or stone till you know exactly what you are going to do, and how you are going to do it. Familiarity with the rules governing the mixing, and with the proportions and quantities, is absolutely essential to success. This is true of all mechanics, and especially true of concrete work. It is not necessarily true that the worker must know the scientific and chemical properties of the work, but he must know the "how." Of course it is better if he has a knowledge of the chemistry of concrete work, but he may produce good results by merely following exactly the formula that has proved effective and advantageous in the hands of experts. These general remarks are made for the benefit of the novice who is thinking of using concrete in the build-

ing of a house, or in the improvement of a home he already possesses. So bear these things in mind:

Do not guess as to measurements.
Do not use less cement than any formula calls for.
Mix very thoroughly.
Put your concrete in place at once.
Use only clean water, and clean gravel or stone.

These five "musts," kept constantly in mind and in practice, are the foundations of success. To ignore any one of them spells failure.

Probably the most important of the above cautions is that relating to the mixing of the concrete. It is in this part of the work that haphazard methods are most apt to creep in, especially if the operations are hurried. The importance of accurate measuring and strict adherence to proportions, cannot be urged too strongly. For ordinary hand work, not more than a cubic yard should be gauged at a time. The worker should have plenty of space for handling the mixture. Faulty concrete is made more frequently as a result of carelessness in gauging than from any other cause; but the blame is usually ascribed to something else. If the measuring of the cement is done by sacks, or of the aggregate by barrow loads, the utmost care should be exercised to insure accurate measurement so that the chances of poor concrete will be avoided.

The aggregate and the cement should be

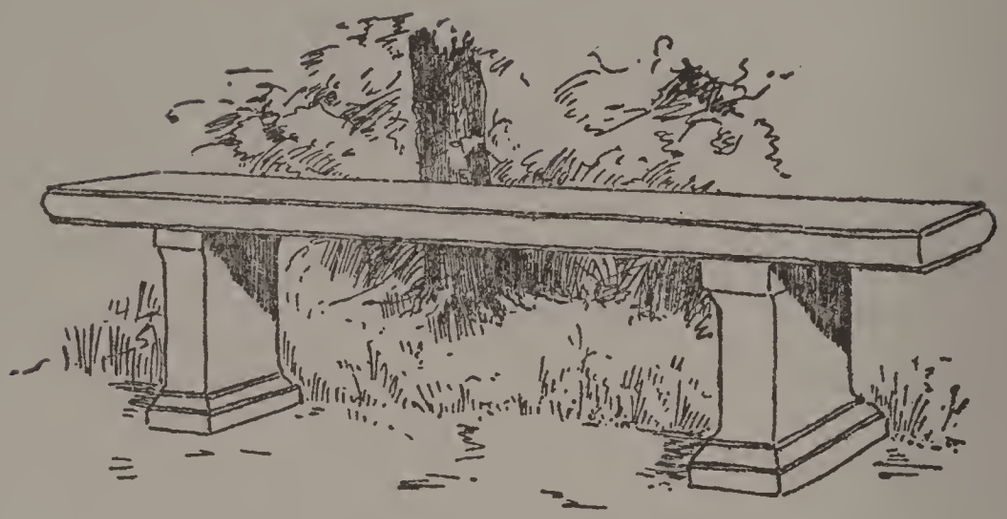
turned over at least three times on the board. If the mixture looks streaky, and does not have a uniform color, it is not fully mixed. When the water is added, it should be applied gradually, all the time being mixed. No more material should be gauged than can be handled quickly. As soon as the concrete is ready, it should be shoveled into pails and carried to the place where it is to be used; it should be deposited in position within 20 to 30 minutes after the first wetting of the cement. Nor should there be any disturbance of it after it is placed, more than is absolutely necessary.

If the mixture does not work well, the sand and cement not filling the voids in the stone, reduce the percentage of stone slightly, but first be sure the concrete is properly mixed. Half-mixed concrete may present features that are entirely eliminated by turning it over once or twice more.

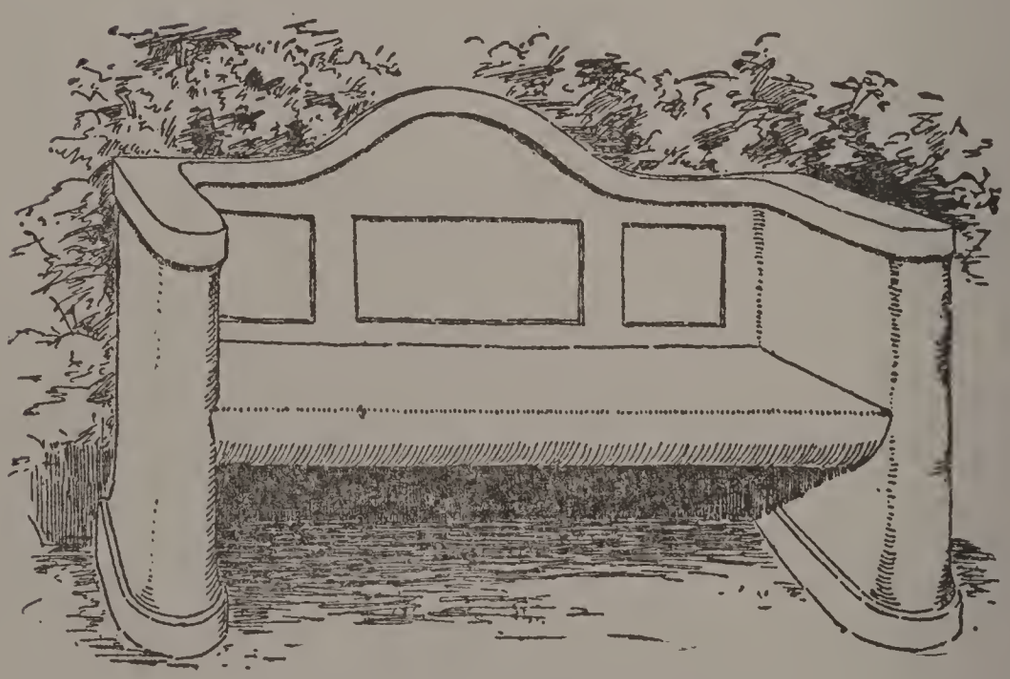
In choosing materials for the mixture, remember that the proper size of stone or gravel will vary with the type of construction.

Remember that the binding value of Portland cement is lowered by exposing the concrete to a hot sun during the first four or five days after it has been placed.

Use anything up to 2½ inches in diameter for foundations or large thick structures. Use 1½ inches and under (generally about ¾ inch), graded, for thin walls and reinforced concrete. Use ½ inch and under for a finish or very hard



Simplest form of seat—Edges should be moulded or rounded, and supports should have a moulded base.



Seat of Romanesque design.

Design for Concrete Garden Seats.

coating. The best results are obtained from a mixture of sizes graded from the largest to the smallest.

If the aggregate is porous, it should be well soaked in water before coming in contact with the cement; otherwise it will absorb the water necessary for mixing and for developing the full activity and strength of the cement.

It occasionally happens that concrete must be **deposited under water.** In such cases, special precaution must be taken to prevent separation of the materials. The governing principle is to see that the concrete shall be disturbed as little as possible in being placed.

There are three methods used:

First, the concrete may be lowered under water to the place of deposit, in a **closed bucket,** which should be provided with an automatically opening hinged bottom, allowing the concrete to slide out gently when its destination is reached.

Second, the concrete may be lowered to place in **tubes.** If only moderate quantities are to be deposited, a small tube—say 4 to 6 inches in diameter—with a removable cap at the lower end, may be used. This is first filled with the mixture, then lowered, the cap removed, and concrete fed through the tube in a continuous stream. Where large quantities are to be placed, requiring a tube of inconvenient weight for handling, this large tube may be lowered empty, the water rising therein. Into this chute the concrete may be dumped until the water has been

displaced. The tube is then slowly raised, allowing the concrete to run out. Under this method, there is always more or less danger of badly washed concrete.

Third, concrete may be placed under water by means of paper bags or of cloth bags of open-mesh weave. Paper bags will retain their shape long enough to permit of proper placing in courses like masonry, and the paper soon loses all its strength through soaking, and allows the bonding or blending of the concrete. A similar union is effected through the open meshes of the cloth bags.

One of the troubles which for a time mystified concrete workers, was the appearance of fine cracks—known as **crazing** or **hair cracks** on concrete surfaces, frequently long after the concrete had set hard. Investigation, however, showed that this disfigurement was entirely superficial. Hair cracks are confined to the surface, being generally of no greater depth or width than a coarse hair; they are no indication of weakness in the concrete. It has long been known that very wet concrete is more apt to craze than dry concrete is. Dry concrete is objectionable to some for the reason that it is lacking in strength and density; and on that account its use is not advocated even though hair cracks are to some extent avoided. Experiments have demonstrated the fact that in wet concrete a portion of the very finest particles of cement is carried to the surface by the action of the

excess water which is being absorbed by the atmosphere. This excess water is to a large extent drawn from the interior of the concrete to the exterior, carrying with it the finer particles, which, being deposited on the surface, form a richer mortar than is contained in the interior. Under certain conditions these finer particles on the surface practically form a coating of neat cement. Neat cements and rich mortars are found to be much more liable to crazing than mortars containing a larger proportion of sand or finely crushed stone. The cracks are due entirely to a contraction of the surface, and not to any contraction of the interior.

The trouble may be almost entirely avoided by seasoning the concrete in a very moist atmosphere or under a cover of very wet sand, or, in the case of blocks, by immersing entirely for a considerable time in water.

In the past, a practice that has been partially effective in overcoming the trouble has been to brush off the surface with a stiff steel brush, or to scrub it with a cement brick and wet sand or carborundum stone, thus partially removing the neat cement face in which the cracks develop. This remedy, however, is only temporary, the cracks being likely to appear months later. The brushing or scrubbing is merely an assistance, the real remedy being to keep the surface continuously and thoroughly wet as long as possible. For permanent results, the only effective remedy is to remove from the surface, as soon as the

forms or moulds are taken down, as much of the excess of neat cement as possible; and then to allow the concrete to harden under conditions practically the same as when hardened under water—keeping it constantly wet during the hardening process by sprinkling, by covering with very wet sand, by inclosing in a very moist atmosphere, by immersing under water, or by some other convenient method of a similar character.

Efflorescence is the name commonly applied to the whitish scum sometimes appearing on stone, brick, terra-cotta, and concrete work, due to the leeching out of lime or other soluble chemical salts. If the scum is due to excess of cement it is known as **laitance.** The **Sylvester** process, consisting of alternate applications of hot soap and alum solutions, has proved effective in its removal. A wash of dilute hydrochloric acid (one part acid to forty parts water) will also be found effective. Efflorescence can be prevented by waterproofing the exterior surface of the wall after the concrete has hardened.

In all concrete work, the essence of economy is found to lie largely in the **proper proportioning** of ingredients according to the materials available and the work in hand, and in **simplicity and duplication of forms.** The designer—especially of a reinforced structure—should therefore eliminate as far as possible all projecting members such as beam panels, cornices, belt-courses, and offsets.

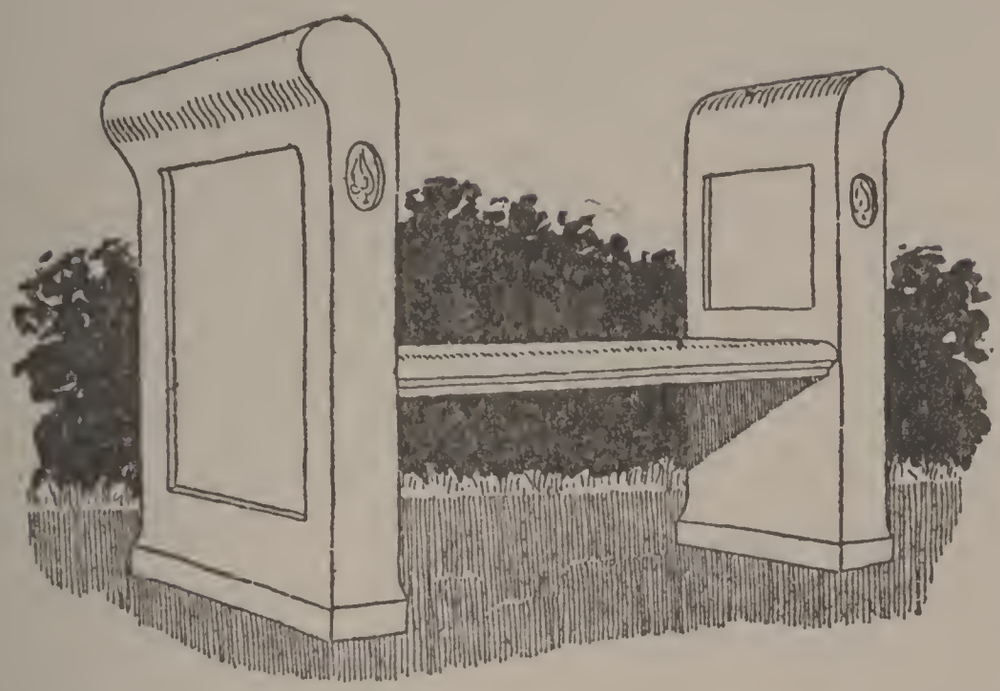
Owing to the comparative youth of this type of structure, it is only within very recent years that architects and engineers have given any very great attention to the development of designs essentially suitable to reinforced concrete. It is the general practice to design in brick, stone, and steel, and then to call upon a reinforced concrete engineer to reproduce a structure in reinforced concrete. This is an imperfect and unscientific method, and unfair to the development of the true value of the concrete structure. Many architects and engineers are, as yet, too unfamiliar with the characteristics of concrete to design a structure solely from that point of view. They think in terms of brick and steel, stone and wood, and design in these materials, and then attempt to adapt concrete to their structure. The architect who would design intelligently for reinforced concrete must think in terms of reinforced concrete, which possesses peculiar characteristics essentially its own. Any design which is to be carried out in this material should be adapted to its characteristics and qualifications. The reinforced concrete building must be essentially a plain building, and its architectural effect must be developed by the the study of the relation of the openings to the masses, together with the assistance of some surface finish suitable to the problem, or some color scheme, applied by the insertion, in the face of the structure, of tile, pebble, or mosaic work.

STRENGTH OF CONCRETE

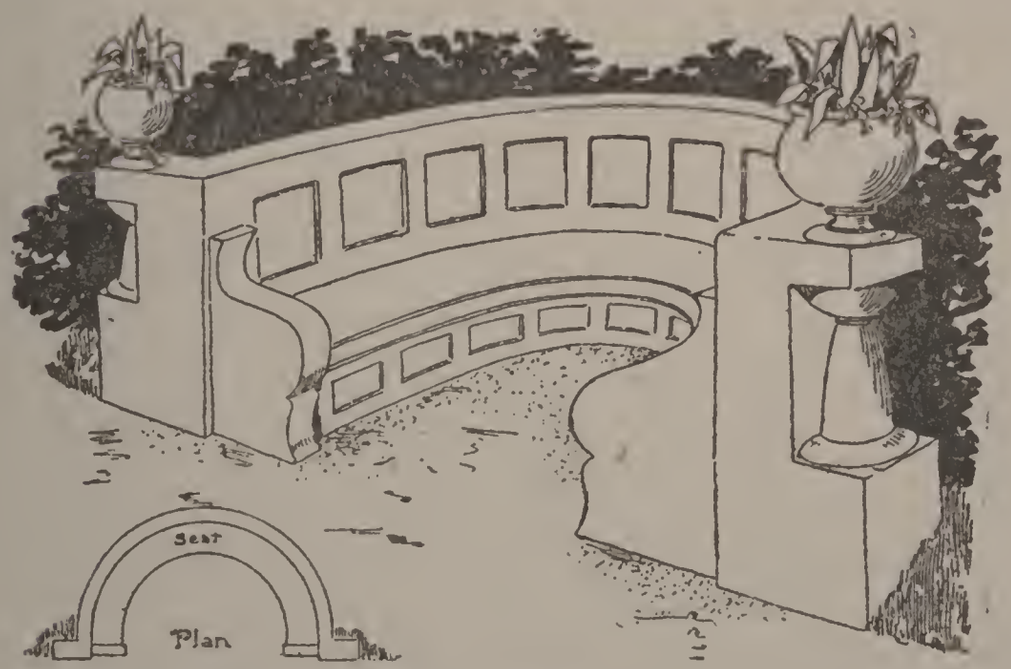
Ice only an inch thick covering a stream or lake will carry safely the weight of a loaded team, whereas a covering of snow a foot thick will not support the weight of a child. What makes the difference in strength between the ice and the snow? Both are of the same chemical composition. The only difference between them—and the only cause of weakness in the snow as compared with the ice—is the presence, in the snow, of a large proportion of air-spaces or voids, greatly lowering its density.

It is much the same with cement mortar and concrete. The **quality of the materials** entering into the mixture will, of course, affect its strength. Trap rock or granite, for example, will give a stronger concrete than sandstone; and a good quality of cement will prove superior to a poorly ground and poorly calcined product. But, other things being equal, the most important factor affecting the strength of concrete is its **density,** and this, in turn, depends upon the **quantity of cement used**—that is, the amount measured proportionately to the volume of the mixed concrete; upon the **sizes of the aggregates** and their **proportional grading of coarse and fine**; and upon the **thoroughness with which the mixing is done** and the ingredients compacted together.

With given proportions of cement, sand, and gravel or crushed stone, the strength will depend



Slab supported at both ends—Design not classic but suggesting spirit of the Art Nouveau.



Semi-circular seat for large garden or public park.

Garden Seat Designs in Concrete.

chiefly on the quality of the materials and the thoroughness of the mixing. The loss of strength due to the use of improper sand may amount to as much as 50 per cent; and a 25 per cent loss of strength may result from carelessness or laxity of methods in mixing.

The strength of concrete as shown under direct compression affords a guide to the **safe vertical loads** that may be placed upon it. The results of tests by Taylor and Thompson are given in Table XVII, showing the safe vertical loads which may be placed upon Portland cement concrete of various mixtures after one month's setting, where the height of the column or mass is not over, say, twelve times its least horizontal dimension.

TABLE XVII

Safe Loads for Portland Cement Concrete under Direct Compression

Proportions	Pounds per Sq. In.	Tons per Sq. Ft.
1:2 :4	410	29
1:2½:5	360	25
1:3 :6	325	23
1:4 :8	260	18

In case of large mass foundations, values one-eighth greater than those given in the above table may be taken.

Where the concrete mass is subjected to vibrating or pounding loads, the values given in the table should be reduced one-half.

The **tensile strength** of concrete is very much less than the **compressive strength,** ranging from one-tenth to one-fifth of the latter. It is also a more uncertain quantity. Experiments by Taylor and Thompson, with mixtures of

average proportions gave the ultimate fiber stress in beams as about one-eighth the breaking strength in compression. As a general thing, the tensile strength is not considered in computing the structural strength of reinforced concrete. It has a certain bearing, however, on the problem, as it affects the location of the neutral axis in beams, and further has an important bearing on the calculated deflection of a beam. The tensile strength of good concrete suitable for reinforced construction, well aged, ranges from 200 to 500 pounds per square inch.

In the matter of the **shearing strength** of concrete, experimenters have reported widely different results, varying all the way from equality with the tensile strength to equality with the compressive strength. The variation depends upon the extent to which the tensile stress in the section in shear is overcome by compression at the same section. Unless a section in shear is in compression at the same time to overcome the tension resulting from the shear, the shearing strength of the section cannot exceed the tensile strength of the concrete.

Weight of Concrete. The weight of a cubic foot of concrete is ordinarily considered as 150 pounds, its variations above or below this depending on the specific gravity of the materials used and the compactness of the mixture. Cinder concrete weighs only about 110 pounds per cubic foot, and its strength varies from one-half to two-thirds that of stone or gravel concrete.

Waterproofing of Concrete

The development of a satisfactory method of waterproofing concrete is one of the most difficult and complicated problems that have exercised the minds of engineers since this material first came to be extensively used as a factor in modern construction. In its entirety, the problem presents a great multiplicity of conditions to be met and ends to be achieved. In some instances—as, for example, in the construction of reservoirs, tanks, and irrigation works—it is necessary to render the structure impermeable to water, even under abnormal conditions of pressure. In other cases—as in the erection of foundations and walls for buildings, where only normal conditions of ground-water pressure and atmospheric moisture are to be met—it is necessary not merely to prevent seepage of water through the structure, but to avoid all tendency even to the absorption and retention of moisture from the air, with their resultant unhealthful dampness. And in still other cases—as in some concrete buildings both of monolithic and of block construction, where all danger of the penetration or absorption of water has been obviated—it is necessary to take special measures to prevent condensation of moisture on the inside.

In view, therefore, of the great complexity of

conditions that characterize the problem, it is highly improbable that any single method of waterproofing can ever be said to meet in the most effective and at the same time the most economical way all possible conditions, and to be unqualifiedly "the best" for all possible cases. As with other engineering problems, the particular features of each individual case call for individual attention and treatment.

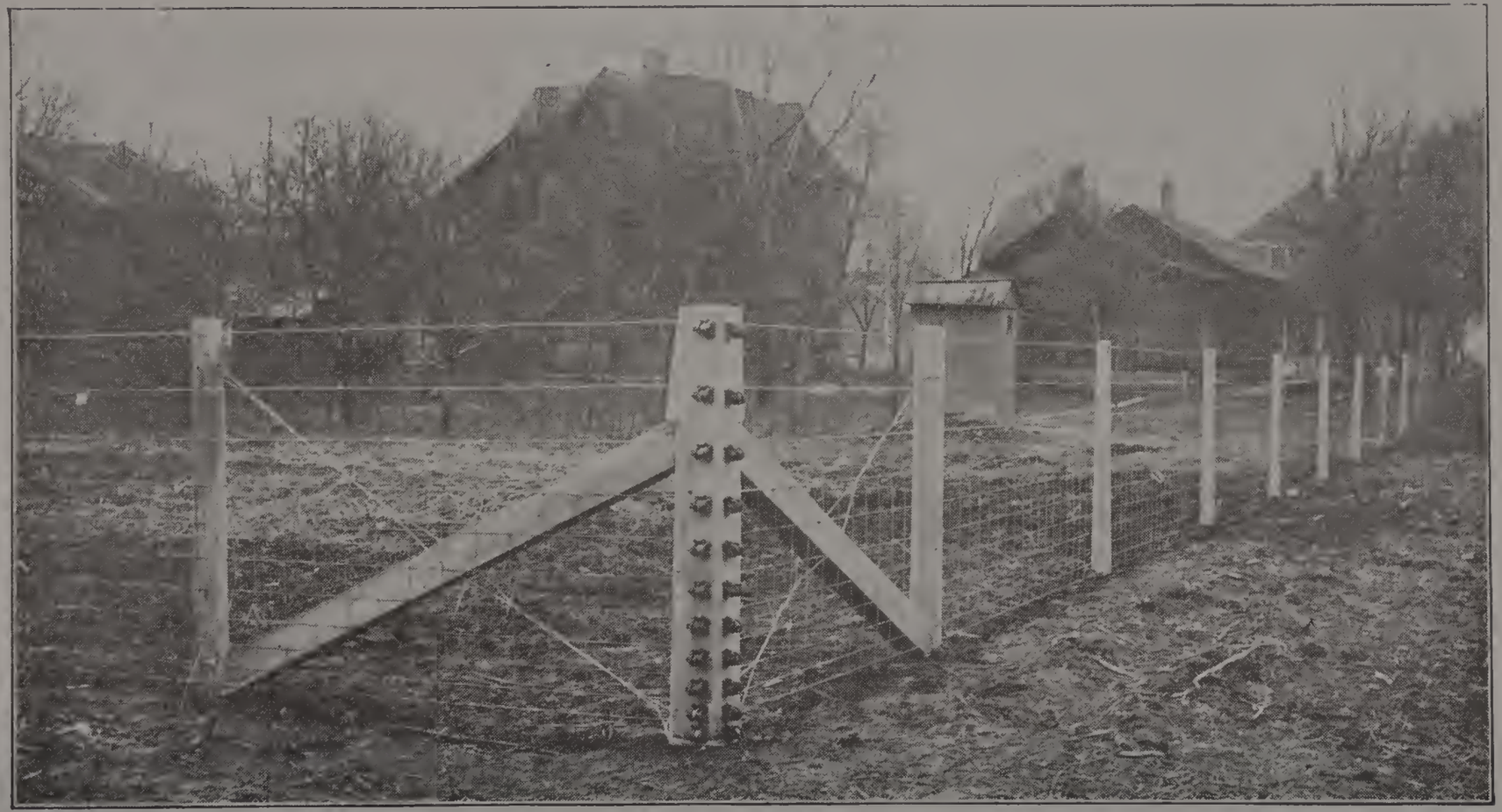
Concrete is not the only porous building material that has been known to mankind; there is abundant authentic evidence to show that it has no monopoly of the unenviable quality of absorbing moisture. Concrete houses are not the only ones haunted with the specters of reeking dampness and mould and other un-hygienic ghosts of bygone times; nor are they the most difficult to flood and flush and brighten with the health-giving stream of modern sunshine and fresh air.

Wood, brick, stone, and, in fact, other building materials in general, with the notable exceptions of steel and glass, share in varying degrees with concrete the quality of being decidedly porous and absorbent; and it is altogether probable that if the principles of grading and proportioning to give mixtures of maximum density had been fully known and appreciated in the early days of the concrete building industry, the cry of "dampness" as regards concrete houses would never have been raised. A concrete house, **properly built**—and it is possible to build it so—is as dry, as light and cheery, as easily regulated

Concrete Vase in Adornment of Terrace Steps.

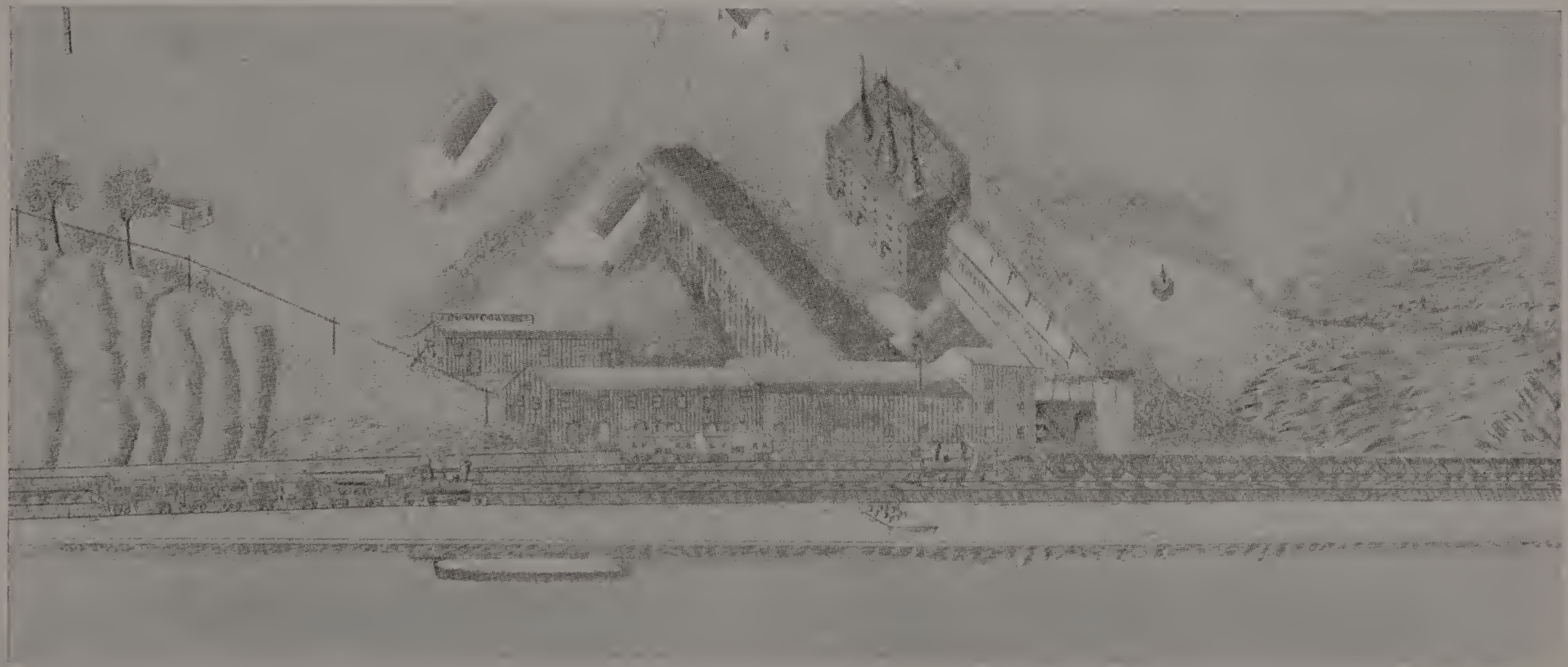
Cup-Shaped Fern or Flower Vase on Paneled Pedestal, of Severely Classical Shape.

CONCRETE SIDEWALK, CURB, AND GUTTER, CHAMBERSBURG, PA.



CONCRETE FENCE-POSTS.
Showing corner post, line posts, and braces.

WALNUT LANE BRIDGE OVER WISSAHICKON CREEK, FAIRMOUNT PARK, PHILADELPHIA, PA.
Connects suburbs of Germantown and Roxborough. A highway bridge of plain concrete construction, the only reinforcement being in some of the walls and columns. Span of main arch, 232 ft.



FIRST PORTLAND CEMENT PLANT ERECTED IN AMERICA.
Located at Coplay, Pa. Reproduced from a sketch made by David O. Saylor about 1873.

in temperature, as well ventilated, and as healthful as one built of any other material.

The importance of waterproofing is emphasized by several considerations. In the case of structures designed to retain water, it is, of course, self-evident. In the case of buildings designed for habitation or for commercial or industrial use, the prevention of abnormal dampness is essential to the health and comfort of the occupants, and has an important bearing on the life of the structure itself. Where the natural conditions of porosity and absorption common to structural materials in general are allowed to prevail unchecked, water is drawn into the foundations from the surrounding soil, and absorbed by the walls from the atmosphere. By capillary attraction, it spreads so as finally to permeate the entire structure, actively attacking and in time corroding and destroying the more or less unstable materials of which the structure is built, and producing damp, clammy walls which constantly foster and disseminate disease. The adoption of an efficient method of damp-proofing and waterproofing is therefore of vital importance, not only preventing the gradual decay and disintegration of structural materials, but going further to establish better hygienic conditions for the benefit of all classes. A practical solution of the problem, moreover, giving effective but reasonably cheap methods of waterproofing adaptable to varying conditions, will greatly promote the cement industry by opening up an

enlarged field of usefulness for concrete, allowing it to be used in a great variety of work to which its formative characteristics peculiarly adapt it, but for which, without protection, it would be of little value.

In many instances, dampness in dwellings does not show up during the cold months of winter or the hot months of summer. This may be due, in the winter, to the presence of heat in a closed room, thus warming the walls and drying out the air as it absorbs moisture from the walls; or in the summer, except in the case of prolonged wet spells, to the frequent changing of the air in the room through the open windows, thus removing the dampness by evaporation. Since we cannot live under the above-described conditions throughout all the year, we should make provision for the exclusion of dampness from our dwellings as much as possible when building. This may be accomplished to a great extent either through the type of construction used, through the manner of protecting the material of the structure against the absorption of water, or by means of a combination of the two methods.

In the use of porous building materials, there may be two conditions to be provided for in keeping out water or dampness: (1) There may be water pressure to be resisted, and actual entrance or percolation of water prevented; (2) There may be a gradual absorption of water by the material, due to porosity and capillary at-

traction. While water may not seem to be present in the material, upon inspection of visible surfaces, it is nevertheless present, and is being constantly evaporated away from the surfaces in contact with moving air. A concrete wall may give out dampness to a room, even if the material is of such a nature that percolation of water through the wall does not actually take place. Provision against the first of these conditions, where water under pressure is to be resisted, is commonly referred to as **waterproofing**; while the protection in the second condition, where water is present simply from absorption and transmission, and under no pressure, is called **damp-proofing.**

Let us see what are the sources from which dampness in a dwelling may be due:

(a) Water or dampness rising from the ground under the building.

(b) Water rising upwards in the materials of which the building is constructed, or from damp earth piled against the foundation of the building.

(c) Driving rains beating against the walls of the building.

(d) Faulty building construction, such as leaks around roof and side walls, or round door- or window-frames; cracked walls, etc.

(e) Sweating of walls.

Hydrostatic Pressure. The amount of pressure exerted by water against walls and beneath floors is frequently underestimated, especially where the hydrostatic head is low or is preva-

lent for but a short time after a rainfall. Table XVIII, showing the pressure exerted on floors and walls by water under various hydrostatic heads, will assist the reader to a clear understanding of the force which waterproofing methods must be designed to withstand.

TABLE XVIII

Pressure of Water under Various Hydrostatic Heads

Hydrostatic Head	Pressure per Square Inch	Lifting Pressure per Square Foot (under Floor)	Average Pressure per Square Foot on Wall Surface Affected
0.5 Ft.	0.21 Lbs.	31.2 Lbs.	15.6 Lbs.
1.0 "	0.43 "	62.5 "	31.2 "
2.0 "	0.86 "	125.0 "	62.5 "
3.0 "	1.30 "	187.5 "	93.7 "
4.0 "	1.73 "	250.0 "	125.0 "
5.0 "	2.17 "	312.5 "	156.2 "
6.0 "	2.60 "	375.0 "	187.5 "
8.0 "	3.47 "	500.0 "	250.0 "
10.0 "	4.34 "	625.0 "	312.5 "
12.0 "	5.21 "	750.0 "	375.0 "
15.0 "	6.51 "	937.5 "	468.7 "
20.0 "	8.68 "	1,250.0 "	625.0 "
25.0 "	10.85 "	1,562.5 "	781.2 "
30.0 "	13.02 "	1,875.0 "	937.5 "
40.0 "	17.36 "	2,500.0 "	1,250.0 "
60.0 "	26.04 "	3,750.0 "	1,875.0 "
80.0 "	34.72 "	5,000.0 "	2,500.0 "
100.0 "	43.40 "	6,250.0 "	3,125.0 "

In order to make sure that a concrete building shall be dry and sanitary, certain precautions have to be taken.

Possibly the first consideration should be that of the location in which the house is to be built. It goes without saying, that, if we dig a hole in low ground, the hole will fill up with water either when dug or after the first spell of wet weather. A cellar placed in a similar location would be subject to the action of water varying from a perceptible water pressure down to ordinary dampness, depending upon the ability of the sur-

rounding earth to carry away the water. Such a cellar should be provided with a waterproofed concrete floor, and walls protected in such a manner that water will neither enter the cellar nor be transmitted to the building walls above.

The side walls of the building should be constructed in such a manner that water from storms will not be absorbed and pass through into the interior of the dwelling. This may be accomplished either by the use of an air-space in the walls; by the use of mortar or concrete treated in such a manner that it will not absorb or transmit moisture; or by a combination of air-space and protective medium.

Cracks due to faulty construction, openings around windows and doors, and other similar openings where water may enter, are more properly considered as points of design than as pure damp-proofing problems, and should be treated as such.

Sweating of interior walls may be due to sudden changes in temperature and atmospheric conditions, the result being similar to that observed on the exterior of a pitcher of cold water on a hot day. If the interior surface of a concrete wall is cold and in contact with warm, moist air, there is a liability to moisture forming on the cold surface. This may be prevented by the use of a proper intervening medium on the wall, which will be of a temperature intermediate between that of the room and that of the wall, or by designing the wall in such a manner

that the inner surface is not directly affected by the temperature of the outside surface. Hollow walls or furred walls should do away with danger of surface condensation.

METHODS OF WATERPROOFING

The various methods devised for the waterproofing or damp-proofing of concrete may be classified under broad headings as follows:

1. **Integral** or **rigid methods.**
2. **Surface** or **external treatment methods,** which may be subdivided into (a) **Paints** or **washes;** (b) **Membrane applications.**

Both of these methods may be—and in many instances are—effectively combined in the same construction.

In the **membrane** or **surface treatment** method, a protective, impervious covering or coating is applied to the surface of the concrete, or placed between successive strata during the erection of the structure, in the form of an elastic membrane or layer which covers and surrounds the parts to be protected.

In the **integral** or **rigid** method, the mass of the concrete itself is waterproofed throughout, prior to setting. The method derives its name from the meaning of the word "integral," the waterproofing material becoming itself a part of the whole mass, as distinguished from the use of a separate and individual protective coating.

Each of the above classes into which waterproofing methods are divided may be further subdivided into a number of special methods differing from one another in marked characteristics.

Integral methods, for example, comprise three great subdivisions as follows:

(a) The use of carefully graded and proportioned and thoroughly compacted mixtures to give maximum density to the concrete.

(b) The introduction of special waterproofing materials into the mixture; these may be in the form of a powder, a paste, or a liquid.

(c) The special treatment of Portland cement itself during the process of manufacture, so that as it comes from the mills it already contains all the waterproofing elements required, with appropriate aggregates, to give an impervious mixture.

The effect desired is produced by properly grading the concrete itself, and then adding special preparations in the form of liquid, powder, or paste, either to the water used in mixing the concrete or to the cement before wetting. Some special brands of cement are waterproofed during the process of manufacture, and do not require further treatment. A further extension of the integral method might include the application of waterproofed mortars to ordinary mass work, where the mortar coating becomes an inseparable part of the mass.

Membrane or Surface Waterproofing

Surface-treatment or **membrane** methods of waterproofing may be subdivided according to the materials used:

(a) One method that has been very widely adopted and has been found of great practical efficiency, even under conditions of great severity, consists in the use of **asphalt** or of asphalt- or tar-product mixtures, either used alone or in combination with felt or similar waterproofing fabrics. This method will be more fully described later.

(b) A method that has been proved effective where the requirements are not very severe, consists in plastering the wall—immediately after the removal of the forms, if possible—with a coat of very rich cement and sand mortar. This coating is usually from one-half to three-quarters of an inch thick, and lime paste is sometimes added for smoothness in working. It is essential that the coating be well troweled and smoothed off, preferably with a wooden float, as the hard skin developed by such treatment is practically waterproof. A neat cement wash is sometimes used, applied with a brush. On horizontal or inclined surfaces, the surface of the concrete should be worked and troweled, giving the effect of a cement coating.

(c) Another method that has given satisfactory results in preventing water penetration and absorption under conditions of moderate

pressure, consists in the application of **washes** that depend, for their effect, upon chemical action. Perhaps the most widely used example of this method is what is known as the **Sylvester process** of waterproofing, which consists in the alternate application of hot solutions of castile soap and alum. The application is preferably made while the concrete is still "green;" but the process may be used for the waterproofing of old walls either of cement or lime plaster, stone, brick, or other more or less porous material. The walls in every case should be clean and as dry as possible, and the temperature of the air not lower than 50° F. The soap is first dissolved in water—three-quarters of a pound of soap to a gallon of water—and, while boiling hot, is spread over the surface with a flat brush. Twenty-four hours later, the alum solution—one pound of alum to eight gallons of water—should be applied in the same manner, at a temperature of about 65° F. The process is repeated every twenty-four hours, four coats being usually sufficient to effect the desired result. From the chemical combination of the soap and alum, an insoluble compound is formed which effectively fills the pores of the structure to an appreciable depth and checks the penetration of moisture.

A process similar to the above in its action has been used for making mortar non-absorbent. Powdered alum (one per cent by weight) is thoroughly mixed with the dry cement and sand; and about one per cent of any potash soap (such

as ordinary soft soap) is dissolved in the water used in mixing the mortar. A wash consisting of five pounds of alum dissolved in two gallons of water, to which one pound of concentrated lye has been added, has been successfully used on green concrete surfaces. Boiled linseed oil, applied in successive coats until it ceases to be absorbed, has also been used effectively. A saturated solution of paraffine in gasoline is also said to give good results.

(d) In addition to the above methods of surface treatment, there are on the market a large number of special patented waterproofing compounds and processes of more or less merit, manufactured according to formulæ, and sold under various proprietary trade names.

It must be understood that there is no hard and fast line of demarcation between the integral and surface methods of treatment. A method that is in its nature essentially integral, involving the incorporation of special materials throughout the mass of the concrete directly affected, may, in the manner of its application, have all the appearance of a purely surface method of treatment, the waterproofed material being spread upon the surface or deposited between successive strata in much the same way as asphalt and other bituminous products are applied.

As already explained, the relative merits of different methods of waterproofing will depend upon the severity of the requirements to be met,

and upon local conditions peculiar to the individual work in hand. It would be beyond the province of this general work of reference to advocate any one method as universally superior to any other, our purpose being merely to place in our readers' hands a clear and intelligent classification and description of the various attempts that have been made to solve this great problem under the conditions of up-to-date practice—a comprehensive summary of the results achieved and the claims set forth.

There are some points of vital bearing on the problem of waterproofing, regarding which there is no dispute. It is universally conceded, for example, that proper proportioning of ingredients, proper grading of aggregates, thoroughness of mixing, and careful methods of placing concrete are factors of the utmost importance. **The densest concrete that can be made with the given materials will be the most impervious to water.** Also, the richer the mix, where no special compounds are used, the more nearly waterproof will the concrete be. It is evident, therefore, for practical reasons, that, for waterproofing work where the concrete alone is depended upon, a tendency to excess of fine materials is better than the reverse. Especially in monolithic construction, it is now generally conceded that a wet mixture, a rich concrete, and a proportioning of aggregates to give great density, are essential for securing a waterproof structure.

Concrete which was not water-tight when

placed has sometimes been observed to become so after the lapse of time. Where constantly subjected to only moderate water pressure, there is a marked tendency of the seepage passages to become closed as the result of the operation of natural causes. Impermeability, like hardness itself, increases with age. Various explanations of this phenomenon have been given. Some think it due to the crystallization, near the surface, of certain materials dissolved by the water during its passage through the concrete; others attribute it to the gradual accumulation of silt carried in suspension by the water.

Where a heavy pressure is constantly maintained against the concrete, on the other hand—and especially if the work is near salt water—these results cannot be looked for. Where the work is of such magnitude as to extend over several days for construction, seepages are likely to occur, especially along the line where one day's work joins that of another, the flow, instead of diminishing, becoming freer with the lapse of time. In such cases a special waterproofing process becomes an imperative necessity. In any case it is advisable to make provision for thorough water-tightness from the start.

Asphalt Waterproofing. Asphaltic coatings, either alone or in combination with felt or other fabric, may be applied to the surface or between two sections or layers of the concrete structure.

The latter method, in which the coating is effectively protected from abrasion, gives the most satisfactory results. A method very frequently adopted is the use of an inch layer of asphalt poured hot between the face of the main wall and a thin protecting wall of brick or concrete built in front of it and carried up as the work progresses.

Asphalt, or **asphaltum** — sometimes called **mineral pitch** or **Jews' pitch**—is a natural bituminous product found in many widely scattered localities. It occurs on the surface and shores of the Dead Sea, which is therefore sometimes called the "Asphaltic Lake," and in many parts of Europe and Asia; but the principal sources of supply are extensive deposits found in the West Indies (notably Trinidad and Cuba), in Venezuela, Utah, California, and other parts of both North and South America. It is brittle, of a black or brown color, and high luster on a surface or fracture; and it melts and burns, when heated, leaving little or no residue. In combination with coal-tar, lime, sand, etc., it is used in the manufacture of a large number of compounds employed for paving, waterproofing, etc.

As might naturally be expected, asphalts differ greatly in their quality and their degree of usefulness for certain purposes. The Utah, Trinidad, and Venezuela products are generally recognized as of the highest grade.

It is essential to a satisfactory waterproofing

material that it should not only be impervious to moisture, but also unaffected by water and weather conditions; it should, moreover, be elastic, so as to allow for settlement and shrinkage in structures without breaking or cracking the waterproof stratum; and it should not dry out

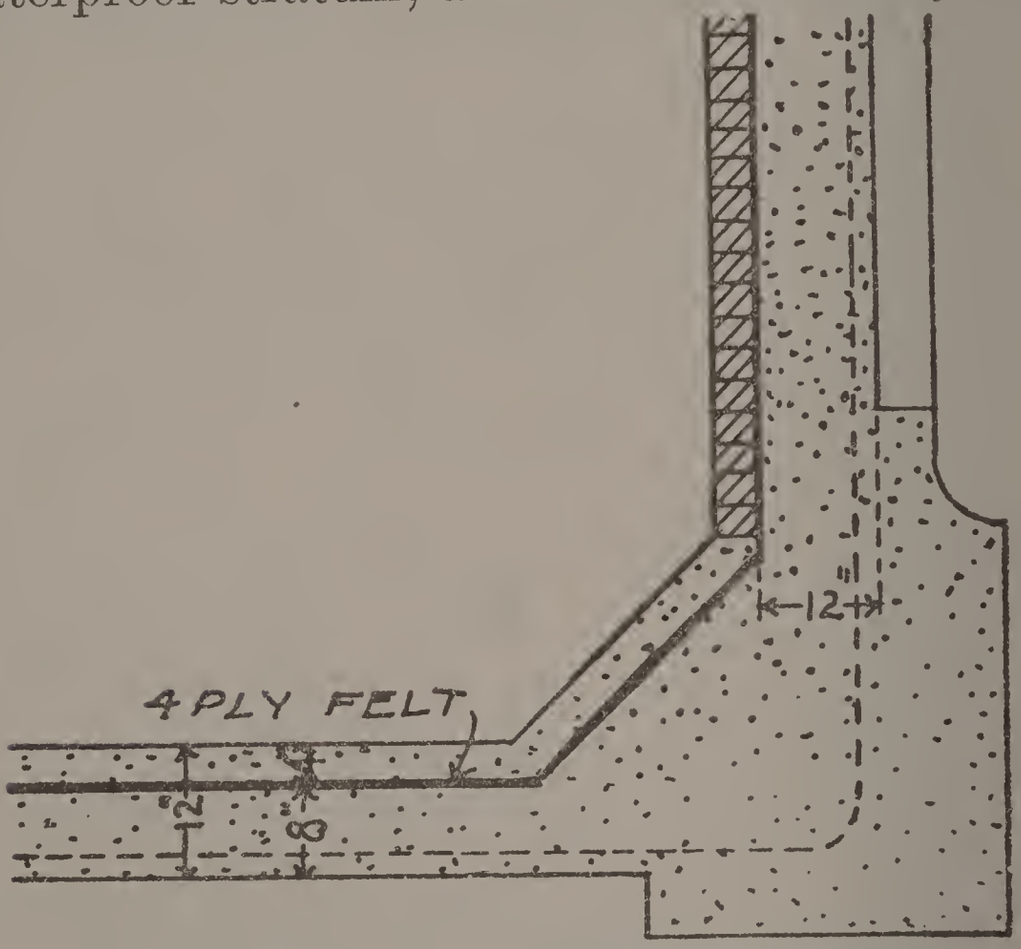


Fig. 13. Method of Waterproofing a Reservoir.

or disintegrate on exposure to air, water, alkalis, or acids.

One special form of prepared asphalt waterproofing on the market is made from a high-grade Utah asphalt containing no impurities which have to be extracted or which are affected by water or weather conditions. The natural asphaltic product used as a basic material in its manufacture, is known as **Gilsonite.**

This waterproofing asphalt is applied at a temperature of about 425° F., with ordinary roofers' mops. In order to overcome the difficulty of making hot asphalt stick to a concrete surface, the manufacturers have developed a special priming paint intended for the first coat to secure the necessary bond.

An effective bonding coat for use with any brand of asphalt waterproofing may be made by cutting asphalt with naphtha, the product being then applied like ordinary paint to the surface, which should first be thoroughly dry.

The following specifications may be taken as typical instructions in methods in general use for the application of asphaltic compounds to various waterproofing purposes:

SPECIFICATIONS FOR RESERVOIR WATERPROOFING

After the first layer of concrete has become set and is perfectly dry, all dust must be carefully brushed off; and on this dry, clean surface, and also in joints between blocks, shall be applied, with ordinary paint brushes, one heavy coat of ..... primer paint, manufactured by ..... (or any paint equal thereto). Over each joint in concrete, there shall be placed a single layer of asphalt-saturated wool felt, not less than 8 inches in width, which felt shall be laid in hot ..... reservoir waterproofing asphalt (or any asphalt equal thereto), which asphalt shall be heated to a temperature of between 425° F. and 450° F. On the primed surface, and also over the strips of felt, shall be mopped a heavy coating of the hot asphalt, which coating must be of uniform thickness of one-eighth of an inch.

The above specification applies to side walls, bottom,

and ends of reservoir. After the waterproofing asphalt has cooled, the next layer of concrete is to be laid over it as provided herein. No asphalt need be applied in the joints of the second layer of concrete, as this layer is simply to protect the waterproofing asphalt.

In reservoir waterproofing, some of the special waterproofing compounds are frequently used, either alone or in combination with asphalt. Very frequently no special provisions are made, except that of special care in the mixing and placing of the concrete. The degree of water-tightness to be attained governs the method to be adopted. It will be desirable to back the reservoir walls with twelve to fifteen inches of clay puddle.

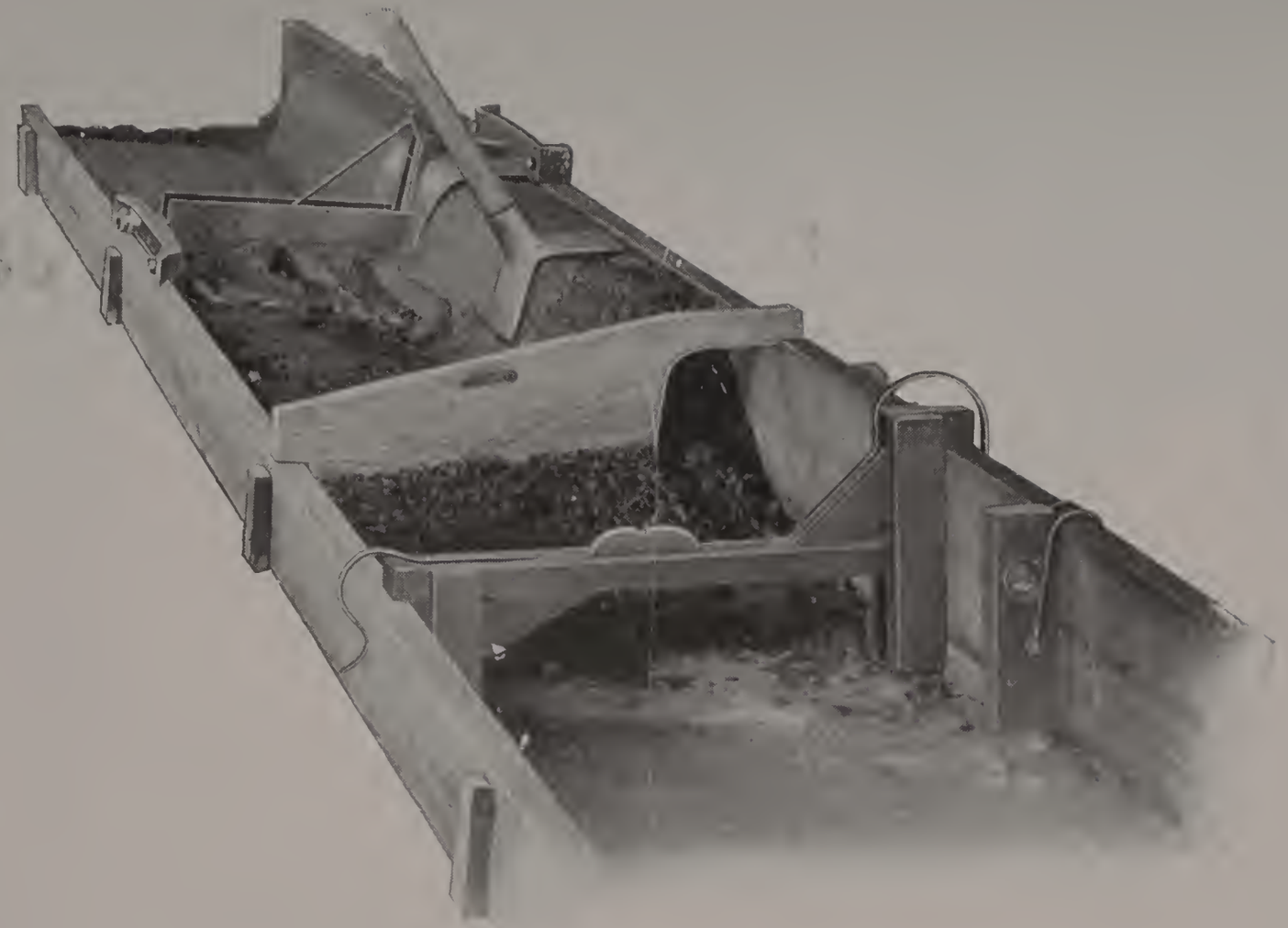
The design of the floor is a most important item in reservoir construction. For small reservoirs it is desirable to put in a floor monolithic with the walls, and to reinforce it in both directions for temperature and shrinkage cracks. In larger work it is customary to place the floor upon a layer of clay puddle—the concrete being separated into blocks for its full depth, and the joints run with hot asphalt filler.

Integral Methods of Waterproofing

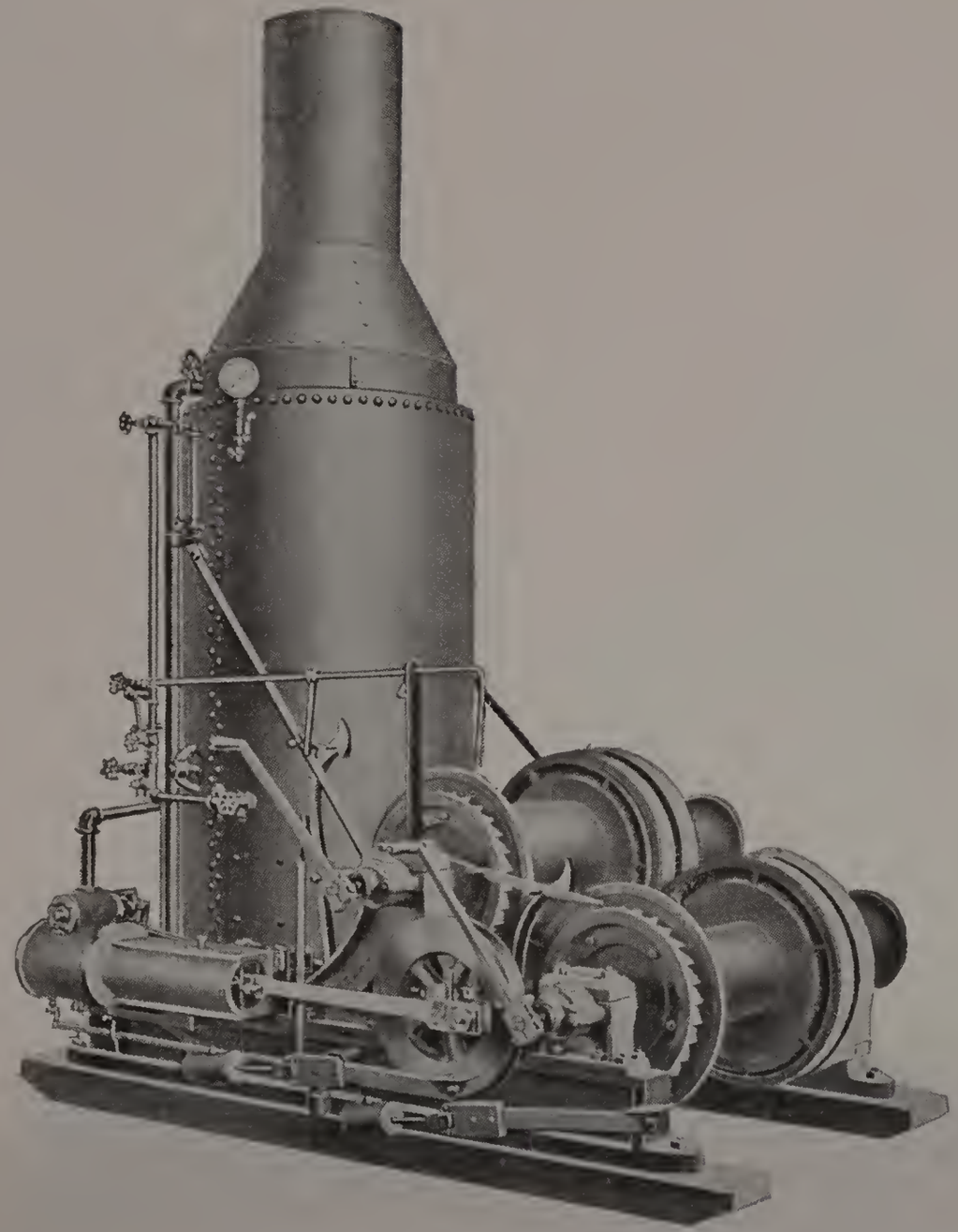
Under this head, as before explained, come all those details that relate to the securing of maximum density in the concrete itself by the use of carefully graded and proportioned and well-compacted mixtures. In addition, however, this heading embraces a great variety of special

BATTERY OF ROTARY KILNS FOR PORTLAND CEMENT MANUFACTURING PLANT AT MONOLITH, CALIFORNIA.

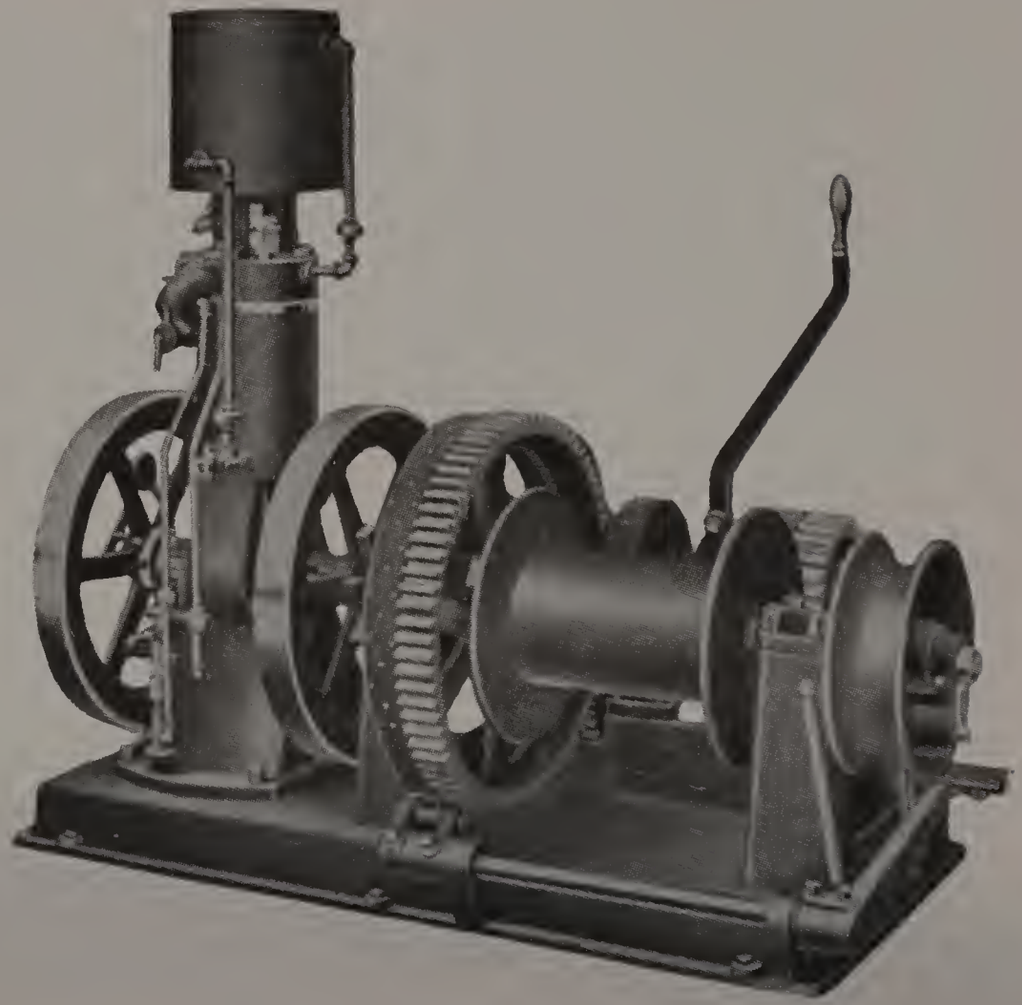
STREET IN WHICH JOSEPH ASPDIN, INVENTOR OF PORTLAND CEMENT, LIVED.
Princess Street, New Road End, City of Leeds, in Yorkshire, England. Aspdin's home was at No. 3—where the men are standing with the cart in front of the door. The roadway here makes a sharp bend to the left.



COMBINATION CURB AND GUTTER OUTFIT.
Showing striker, curved tamp, plumb, and level.



STEAM ENGINE AND HOIST FOR OPERATING ELEVATORS, DERRICKS, ETC.



GASOLINE ENGINE AND HOIST DRUM.

products intended for direct incorporation in the concrete mass. The majority of these on the market are in powder form, but some are in the form of liquid or paste to be added as a solution.

Hydrated Lime. One of these "integral" materials which is very widely used, and which involves no secret formula for manufacture though frequently sold under special trade brand names, is hydrated lime. It consists of a very high grade of calcium oxide, almost 100 per cent chemically pure. It is frequently mixed dry with the cement and aggregates, before the addition of the water. While the amount to be used should vary somewhat with the character of the work required, an admixture of 10 to 25 per cent by weight of hydrated lime to the amount of the cement used will greatly increase the water-tightness of the concrete and make a rich mixture practically waterproof. The action of the lime seems to depend largely on the fact of its extreme fineness, which, it is claimed, exceeds that of the finest ground Portland cement, and renders it capable of filling smaller voids, thereby increasing the density of the mixture. It increases the plasticity of mortar and concrete, and their ease of working under the trowel, thus adding to the capacity of workmen in laying brick, blocks, stone, etc. It also greatly increases the adhesive power of mortar, the lime retaining moisture longer than cement alone, thus retarding the set and enabling the mortar to penetrate deeper and gain a stronger grip.

In a paper read before the 1908 annual meeting of the American Society for Testing Materials, and based on a number of careful tests, Sanford E. Thompson announced his conclusions regarding the effect of hydrated lime upon the permeability of concrete to which it is added, as follows:

1. Hydrated lime increases the water-tightness of concrete.

2. Effective proportions of hydrated lime for water-tight concrete were found to be as follows:

One part Portland cement; 2 parts sand; 4 parts stone; add 8 per cent hydrated lime.

One part Portland cement; 2½ parts sand; 4½ parts stone; add 12 per cent hydrated lime.

One part Portland cement; 3 parts sand; 5 parts stone; add 16 per cent hydrated lime.

These percentages are based on the weight of dry hydrated lime to the weight of dry Portland cement.

3. The cost of large waterproof concrete structures may be frequently reduced by employing leaner proportions of concrete with hydrated lime admixtures; and small structures, such as tanks, may be made more water-tight.

4. Lime paste made from a given weight of hydrated lime occupies about 2¼ times the bulk of paste made from the same weight of Portland cement, and is, therefore, very efficient and void-filling.

Hydrated lime will not swell or expand in concrete as will ordinary free lime. The swelling of free lime in concrete after the work has set and hardened, sets up internal stresses which may cause the work to crack and peel off the surface, and may also give rise to blow-holes. These undesirable results, it is claimed, are avoided by the use of hydrated lime.

Many of the advantages claimed for this material are based on considerations of economy. The addition of a small proportion of hydrated lime will greatly increase the amount of work that can be done with a certain weight of cement.

The quantity of lime that can be added to a mortar depends entirely upon the amount of Portland cement that is present in the mixture. The best results seem to be attained when the proportion of cement to lime is as 1 to 1, although proportions ranging from 1 to ½ up to 1 to 2 have been used. The mortar made from one part Portland cement combined with six parts sand and one of lime paste, seems to give the best results. The sand-carrying power of the cement is almost doubled by this mixture; and the mortar is easy to work, of great strength, hardening rapidly in air, and offering a perfect resistance to the weather.

Another authority on hydrated lime, Robert S. Edwards, embodied the results of his observations on the active properties of this useful material, in a paper read before the Lime Manu-

facturers' Association. His remarks are of special interest because of the extent to which hydrated lime is now used in concrete road and pavement construction.

The problem of reducing the amount of water which leaches from a newly laid concrete road surface is a serious one. Several palliatives have been proposed, among them the addition of hydrated lime to the concrete. Whether the strength and hardness are affected to the extent of over-balancing the advantages derived from the increased water-tightness of the concrete, has not been determined.

The general conditions under which concrete pavements are placed are severe, as the majority of work is usually done in the dry spring and summer months when temperatures are high, causing excessive evaporation. The concrete is generally poured on an earth or clay sub-base, in a thin slab varying between 4 and 7 in. in thickness. This condition alone makes it almost impossible to secure uniformity throughout the concrete mass, so that, after hardening, the concrete road slab is subject to far greater variation, due to the segregation of the coarse aggregate from the mortar, than is found in other forms of concrete work. This, of necessity, causes unevenness throughout the concrete, and the excessive cracking and unraveling so often seen in poorly laid concrete roads is directly due to this fact.

It is the writer's opinion that the primary cause of cracking in concrete pavements is due to the loss or leakage of varying portions of the mixing water from the concrete by seepage through the sub-base, as well as by evaporation from the surface of the concrete, which leaves the concrete road slab in such a condition that at later times it will alternately absorb and give up water, depending on the season of the year; and that expansion and contraction of concrete and any movement in its

volume are due infinitely more to this alternate wet and dry condition than to any temperature change from hot to cold without presence of moisture.

The cracking which is directly attributed to the change in the condition of the sub-base, either in settlement spots or in drying out in shrinking, is primarily due to this cause, which is greatly helped by unevenness and variability of the concrete mixture.

There are extremely few, if any, concrete pavements, individual slabs of which can be considered entirely uniform.

Hydrated lime is a product formed by the addition of accurate quantities of water to known weights of freshly burned quicklime, the finished material being a flour-like powder of great fineness and covering capacity, having more than twice the volume of the same weight of cement in its dry state.

The use of hydrated lime as a void filler in concrete mixtures, and for rendering concrete mixtures more water-tight, dates back several years. Numerous tests show that a replacement of from 10 to 15 per cent of cement by hydrated lime in rich concrete mixtures does not decrease the compressive strength of the concrete after three to four months' time, and ultimately increases the strength and permanence of the concrete. It apparently makes but little difference as to its action as a void filler, whether the hydrate is manufactured from a dolomitic or high magnesia lime or a high calcium lime—it being necessary only to have a product which contains no free lime or unslaked particles. The proper hydration or dry slaking of lime reduces it to a finer degree of subdivision than can be accomplished by any mechanical means.

The amount of water required to convert the dry hydrated lime into a plastic paste varies from 50 to 70 per cent of the weight of the lime; while, to obtain a mortar

of similar consistency with Portland cement, an addition of 25 to 30 per cent of water is required.

Unlike Portland cement, however, the addition of water to hydrated lime does not create any chemical reactions. There is simply a lime paste formed which holds its excess water for a long time. Upon the addition of small quantities of hydrated lime, amounting to 10 or 15 per cent, to the weight of cement used in concrete mixtures and the ordinary mixing of such mixtures, the hydrate, which has absorbed a large amount of water, corresponding to its weight, is thoroughly disseminated throughout the concrete mass; and, due to its fine plastic conditions, it is forced immediately into places in the concrete which the cement cannot reach.

Concrete so mixed, on leaving the mixer, flows more readily into place, and the coarse aggregate has much less tendency towards segregation in the concrete mass. In other words, the extremely finely divided condition of the moistened hydrated lime paste has increased, to a marked degree, the covering or spreading quality of the cement, and reduced, to a similarly marked degree, the friction between particles of fine and coarse aggregate.

This answers the question "Why does hydrated lime benefit concrete?" The action is purely a mechanical one, and can be compared to the oiling or greasing of a shaft or bearing. The property which hydrated lime has of absorbing and retaining large percentages of water, offers a ready solution to the problem of finding a means for keeping and holding moisture in freshly poured concrete pavements until the slower-acting cement-hardening process can utilize it.

It is obvious that small percentages of hydrated lime, when added to concrete mixtures in road work, will accomplish the following things:

1. Renders the concrete highly plastic and homogeneous, thus producing density and uniformity in the finished concrete. This condition adds much to the life

and efficiency of the road, because of the uniform resistance to wear and other stresses.

2. Keeps a certain amount of excess moisture in the concrete while setting.

3. Renders the concrete mass more nearly watertight, thereby preventing the alternate wetting and drying-out of the finished concrete.

4. In large pieces of work, these properties given to concrete by hydrated lime would materially reduce the labor in spreading and bringing the concrete to a uniform surface, which is of great importance in paving work.

Practical Instructions for Waterproofing

Where any of the commercial preparations are to be used directly in the concrete, care should be taken to determine the degree of reliability to be placed in them. The manufacturer should be willing to furnish dependable information in regard to the effect on the strength of concrete, effect on steel reinforcement, effect of acids or of temperature conditions, etc. The general principle of such preparations is more or less of the nature of chemical action, and depends either upon the filling of the pores of the concrete with a water-repelling substance, or upon the depositing of insoluble material in the pores.

It is claimed that an integral compound should be in a fine state of subdivision in order to be most effective, so that it may be intimately mixed with the cement and not impair the strength of the mixture. Dissolving the com-

pound in the mixing water provides a ready means for even distribution.

It must not be understood that an integral waterproofing compound will make a poor grade of concrete waterproof, although it may serve to

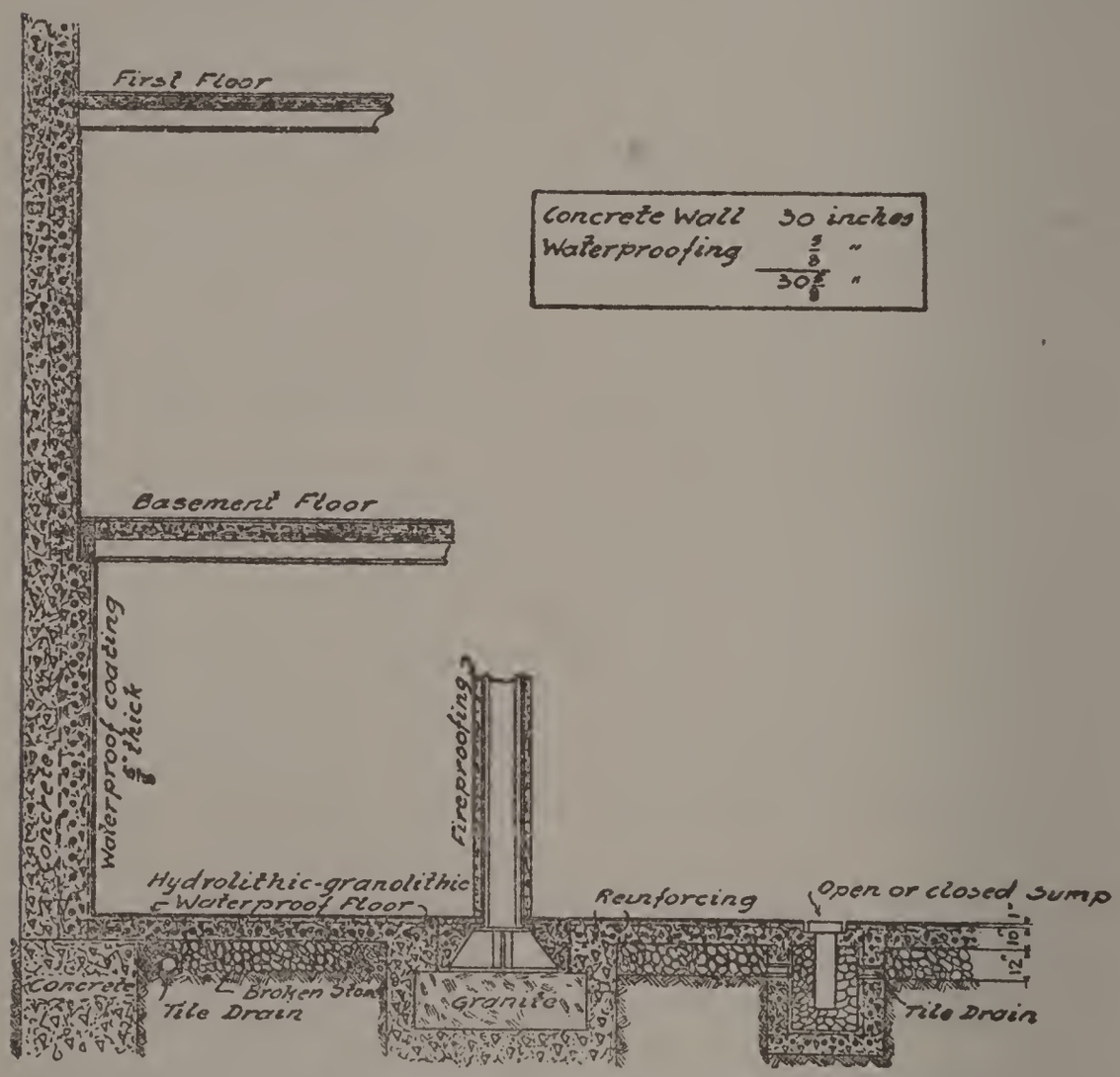


Fig. 14. One Method of Waterproofing a Building.

Walls and floor are placed monolithic; waterproof coating applied on inner surface.

render it less susceptible to ordinary dampness; nor should the importance of correct mixtures of cement and aggregates be lost sight of where dependable results are desired.

Mixtures of cement and aggregates often recommended where water or dampness is to be

excluded, are as follows: For concrete using broken stone varying from ¼-inch to 1½-inch diameter, a mixture of 1 part Portland cement; 2 parts clean, well-graded sand, with a slightly larger proportion of fine grains than is recommended in making concrete of maximum strength; and 4 parts stone.

Where small stone ½-inch and under, and containing dust, is used, a mixture of 1:1:2 will give better results than a 1:2:4.

Recent tests indicate that gravel produces a more water-tight concrete than crushed stone under similar conditions.

Mixtures for mortar facings vary according to location. A 1:3 mixture of Portland cement and sand is often recommended for exterior work above grade, while a 1:2 mixture is used on interior floors and work below grade.

The addition of thoroughly hydrated lime in an amount equaling about 5 per cent of the weight of cement used, is claimed to aid in rendering concrete mixtures less permeable.

One type of surface coating, as already described, includes preparations which are applied in the form of a paint or wash. Although this method is considered by many engineers to be more properly a damp-proofing method than a waterproofing method, many manufacturers claim that their product, even when applied as a surface coating, will resist ordinary pressure of water and will wear well when exposed to the action of water.

From the manner of application, it would seem that surface preparations would be best fitted for use in locations where little or no wear is likely to occur. Such preparations are used to a great extent where it is desired to keep dampness out of the parts of a structure above ground, and to serve as a skin coating on the interior of water or other fluid containers. Alter-

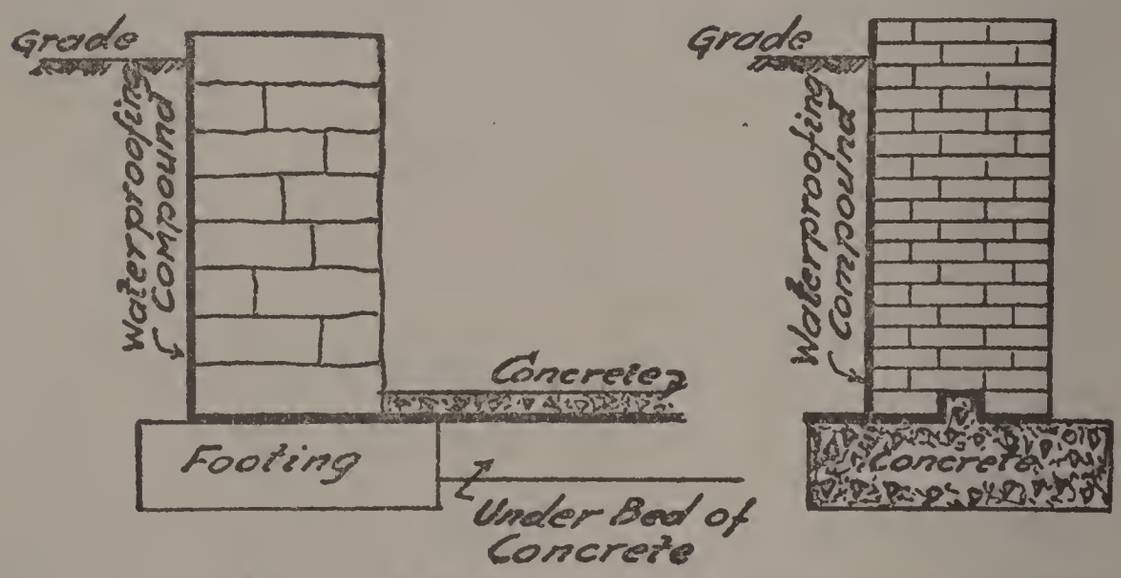


Fig. 15. One Method of Waterproofing Stone and Brick Buildings.
Waterproofing applied outside walls and over footings.

nate washes of soap and alum solution, paraffine washes, bituminous washes, cement grout containing a water repellant, and many other commercial preparations, are used with a greater or less degree of success.

The other type of surface coating is often called the "Membrane" method, and derives its name from the manner in which the continuous, elastic, impervious sheet of bituminous material or patent compound surrounds the structure to be waterproofed. The materials used for this form of waterproofing are coal-tar pitch,

asphalts, asphalt mastic, and specially prepared compounds. The pitch and asphalts are applied hot in the majority of cases; and, where severe conditions are to be provided for, layers of felt or burlap are used with the preparation. For the exclusion of ordinary dampness, two or more coats of the preparation without the felt may be used directly upon the surface to be pro-

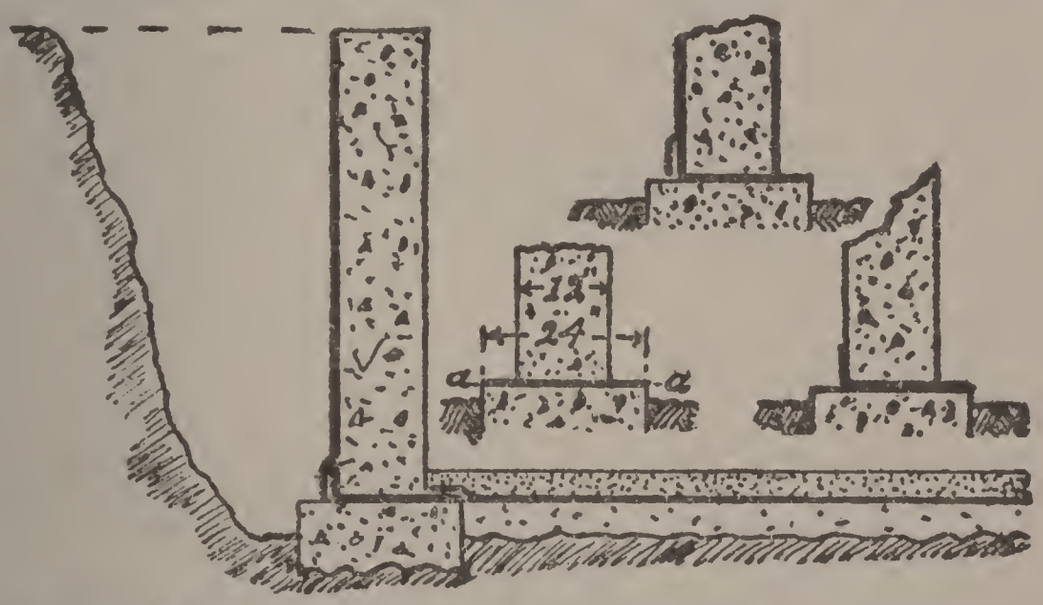


Fig. 16. A Reliable Method of Waterproofing or Damp-Proofing below Grade.

tected; but care should be taken that all parts of the surface are well covered.

Where water pressure is to be resisted, as in Figs. 15, 16, and 17, alternate layers of felt or burlap (either plain or saturated with the bituminous material) and the asphalt or tar preparation are laid in such a manner as entirely to envelop the structure. Care must be taken that all joints lap, and that openings for pipes, etc., are protected. The number of "ply" necessary depends upon existing conditions, and particularly upon the pressure of water to be re-

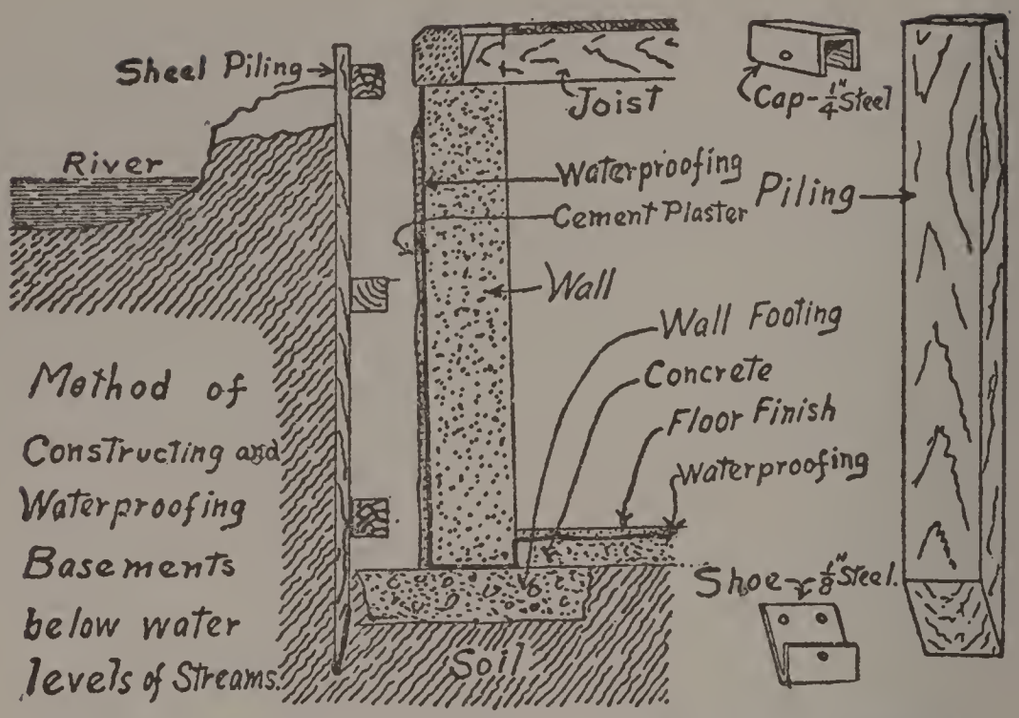


Fig. 17. Cellar Waterproofed by Membrane Method.

sisted. "One ply" is commonly considered to mean one layer of the felt or burlap coated on both sides with the waterproofing preparation.

For ordinary building foundations and work of a similar nature where water pressure is to be

TABLE XX

Number of Ply to be Used

Membrane Method of Waterproofing

Head of Water	Material			
	Coal Tar and Felt	Commercial Asphalt and Felt	Special Felts and Compounds	Asphalt Mastic
0	2	2	1	1/4 inch thick
1	3	3	2	5/8 " "
2	4	4	3	5/8 " "
6	5	5	4	5/8 " "
8	6	6	5	3/4 " "
10	7	6	6	3/4 " "

resisted, Lewis and Chandler recommend the numbers of ply indicated in Table XX for various water pressures expressed in feet depth of water which is to be resisted.

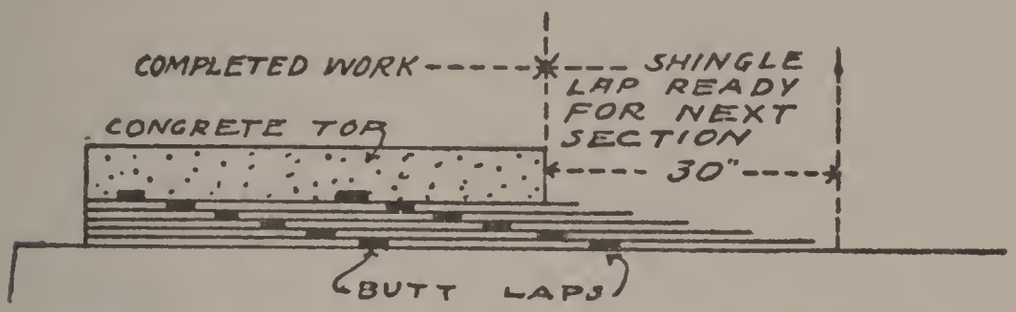


Fig. 18. Method of Arranging Laps in Laying Felt.

The manner of laying a 6-ply coating is shown in Fig. 18.

The membrane method, as described above,

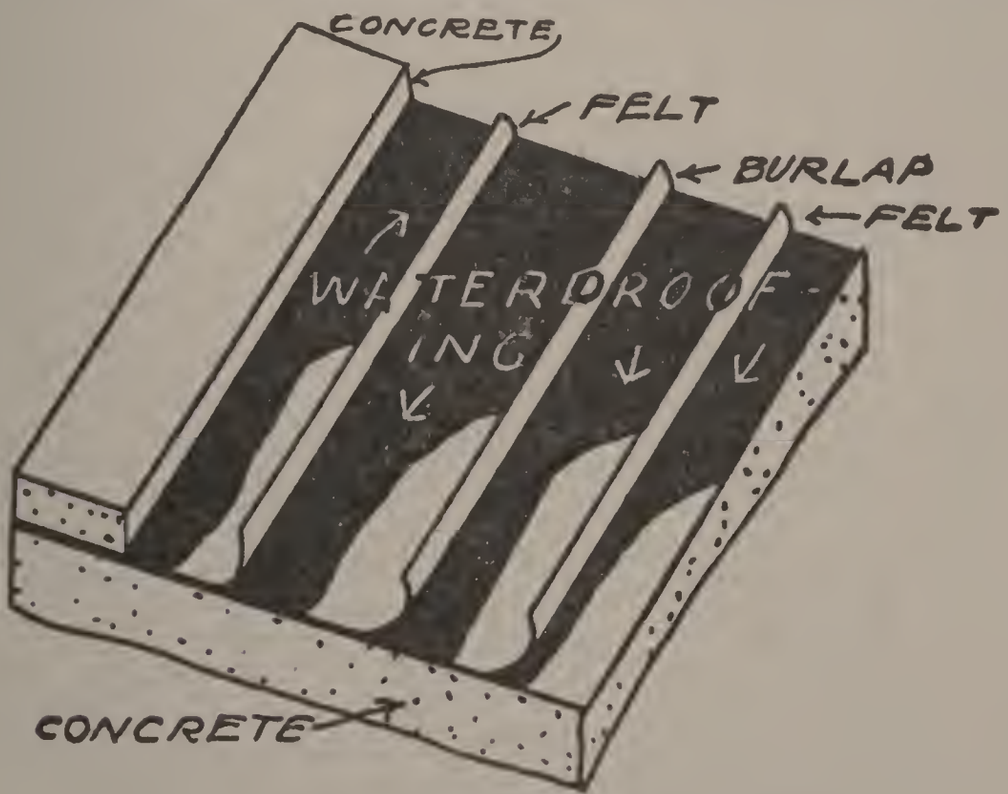


Fig. 19. Method of Laying 3-Ply Coating.

is especially adapted to waterproofing structures during the course of erection, when all parts of the structure to be waterproofed are easily

TABLE XXI

Outline of Modern Waterproofing Processes

Methods Available for Various Structures

	Nature of Structure	During Construction (New Work)	Remarks	After Construction (Old Work)	Remarks
Water Supply and Sewerage. Buildings.	Exposed Walls	D	For Damp-proofing Only	D	Principally for Brick and Stone Walls; Not Advisable on Smooth Concrete Walls
		B, C	For Damp-proofing and Preservation of Stone	B, C	
	Superstructural Floors	I, K, J, G, M	For Bathrooms and Floors Liable to be Wet	G, M	For Dampness Only or Pressure Work
	Foundation Pits	I, J	For Resisting Dampness Only	G	
	Foundation Trenches	I, J	For Resisting Dampness Only	G	
	Foundation Footings, Walls, and Floors	I, J	For Resisting Dampness Only	G	
	Walls, Reinforced	G, K, L, M	For Resisting Water Pressure	G, M	For Resisting Water Pressure
	Walls, Not Reinforced	K, L, M	For Resisting Water Pressure	G	For Resisting Water Pressure
	Floors, Reinforced	G, K, L, M	For Resisting Water Pressure	G	For Resisting Water Pressure
	Floors, Not Reinforced	K, L, M	For Resisting Water Pressure	G, M	For Resisting Water Pressure
	Column Footings, Heavily Loaded	O		B, C	
	Concrete Blocks, etc	G, B, C		B, C	
	Preservation of Stone	B, C	Also for Preventing Efflorescence		
Rail-Roads.	Subways and Tunnels	K, L, M, G		G, H	
	Bridges	N, K, L, M		G, M	
	Culverts	E, F		G, A, B	
	Retaining Walls, Arches	E, F, K, L		G, A, B, H	
		E, F, K, L, M		G, A, B, H	
	Reservoir Banks	K, L, M		K, L, M	
	Dams	E, F, H			
	Conduits	E, F, G		A, B	
	Tanks	G, F, B		B, A	
	Chambers	G, F, B, A		G, A, B	
	Sewers	E, F, K			
	Manholes	F, G		G, H	
1	2	3	4	5	6

TABLE XXII

Index and Description of Waterproofing Methods

Method	Classification	Material Employed	Manner of Application	Position in Structure	Thickness, etc.	Remarks
A	Surface Coating	Solutions of Alum and Soap (Sylvester Process)	As a Paint	On Exterior Surface	4 to 7 Coats	Applicable to New or Old Work; Not to Underground Work
B	Surface Coating	Paraffine in Saturated Solution	As a Paint	On Exterior Surface	2 to 3 Coats	Not to Underground Work Also a Preservative for Building Stone
C	Surface Coating	Melted Paraffine Wax Applied Hot	As a Paint	On Exterior Surfaces (Surfaces Previously Heated)	Penetrates $\frac{1}{4}$ to $\frac{1}{2}$ inch	Also a Preservative for Building Stone
D	Surface Coating	Proprietary Bituminous Compounds, Applied Cold	As a Paint	On Interior Surface	2 Coats	Used also as a Substitute for Furring and Lathing
E	Integral or Rigid	Masonry or Concrete Correctly Proportioned				Available Only during Construction
F	Integral or Rigid	Masonry or Concrete Correctly Proportioned with Cement Waterproofing Compound	In the Body of the Work			Available Only during Construction
G	Integral or Rigid	Cement Mortar with Compound	As a Plaster or Stucco	On Interior Surface	1″ to 2″ on Floors $\frac{1}{4}$″ to $\frac{3}{4}$″ on Walls	For New Work or Remedying Defective Work
H	Integral or Rigid	Cement Mortar or Bituminous Grout	Pumped under Pressure	In Interior of Mass		Employed Principally to Fill Voids Otherwise Inaccessible
I	Membrane or Elastic	Asphalt or Coal Tar Pitch with Felt or Burlap	In Alternate Layers	On Surfaces Exposed to Water	1 to 3 Ply	Applicable Only during Construction for Subsurface Work. To Resist Dampness Increase Thickness According to Pressure
J	Membrane or Elastic	Proprietary Bituminous Compounds, Applied Cold with Felt or Burlap	In Alternate Layers	On Surfaces Exposed to Water	1 to 3 Ply	
K	Membrane or Elastic	Coal Tar Pitch Applied Hot with Felt	In Alternate Layers	On Surfaces Exposed to Water	2 to 10 Ply	For Water Pressure Work
L	Membrane or Elastic	Asphalt Applied Hot with Felt or Special Fabrics	In Alternate Layers	On Surfaces Exposed to Water	2 to 8 Ply	Asphalt Not to be Used in Ground Polluted by Gas-Drip, etc.
M	Membrane or Elastic	Asphalt Mastic or	As Plaster or Coating	On Surfaces Exposed to Water	$\frac{1}{2}$ Inch to 1 Inch	
N	Membrane or Elastic	Asphalt Mastic Alternating with Saturated Felt Layers		On Surfaces Exposed to Water	$\frac{1}{4}$″ to 1″ Mastic 2 to 5 Ply Felt	Useful Particularly for Bridge Waterproofing Subject to Vibration
O		Sheet Lead or Copper		Under Column Footings		Used as Substitute for Felt When Column Loads Are Very Heavy
7	8	9	10	11	12	13

reached. At this time, the foundations and walls are in such condition that the waterproofing layers may easily be applied to the surfaces which receive the water first. After these surfaces have once been covered by a back-filling of earth, or support some other part of the structure, the membrane method is difficult to apply to best advantage.

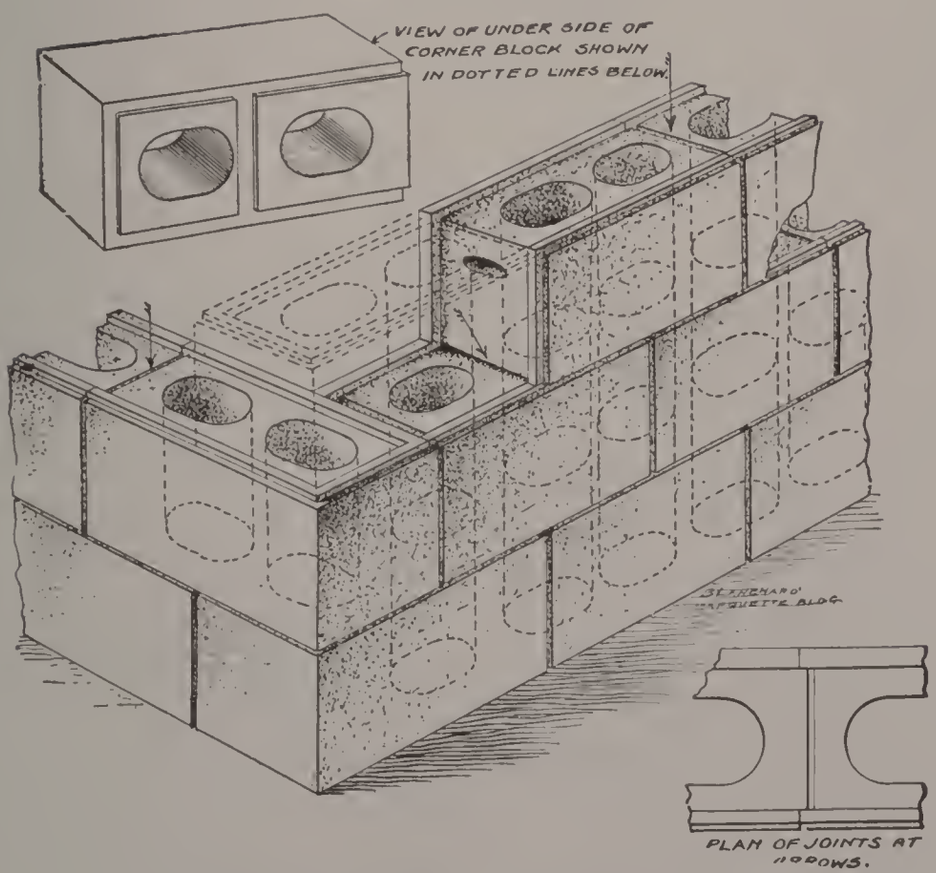
Tables XXI and XXII contain valable information in regard to the classes of damp-proofing mediums just described, and recommendations for use of same in various locations. These tables are taken from a paper presented before the American Society of Engineering Contractors by Myron H. Lewis, C. E.

In these tables, columns 3 and 5 give the methods of protection for the different structures listed in columns 1 and 2. Column 5 gives methods available for structures already erected, and for remedying leaky conditions.

It is not claimed that the arrangement of methods will in all cases be decisive, or that some other methods not listed may not be employed. The object is to prevent the use of methods in places where such a use would be of but little service, or absolutely wrong.

In looking back to the causes of dampness in buildings, referred to earlier in the article, we may eliminate the first one—namely, dampness rising from the ground—by providing a properly damp-proofed cellar floor and damp-proofed cellar walls. The type of floor and walls required,

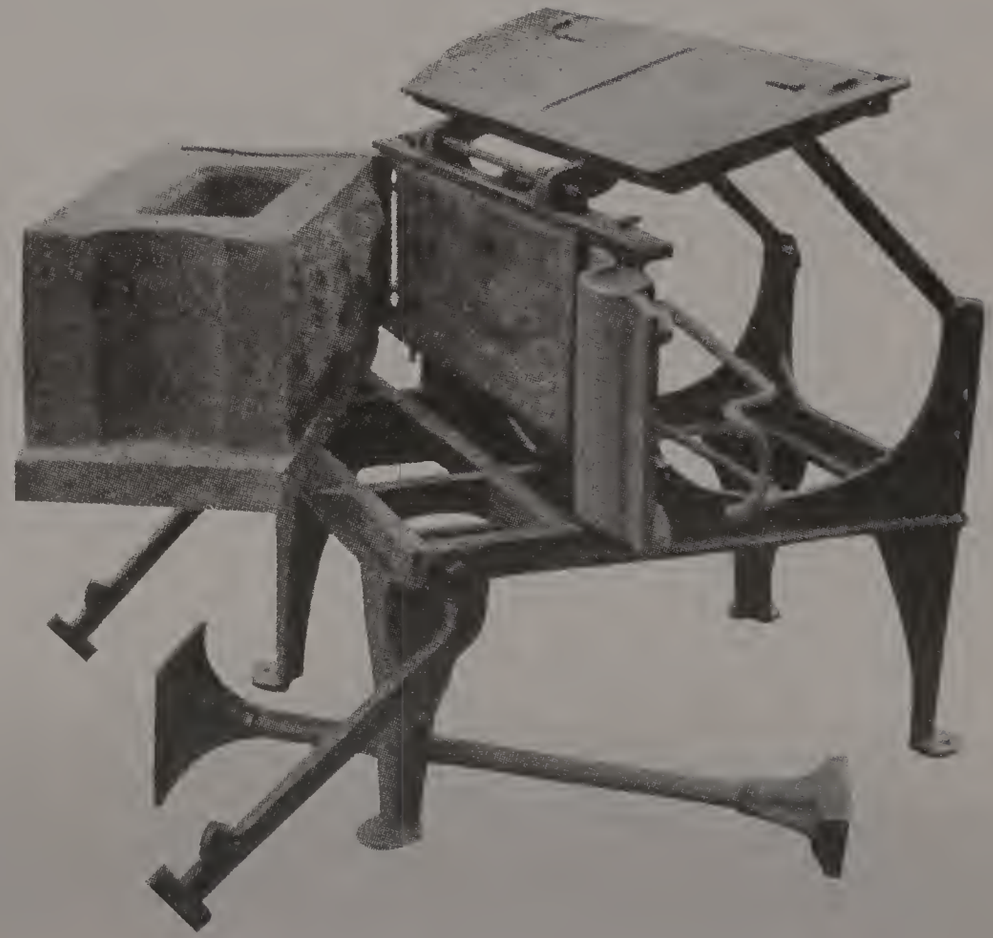
INTERLOCKING CONCRETE BLOCK MACHINE.



DETAIL OF WALL CONSTRUCTION.

Blocks have self-lining and interlocking features that enable them to be placed by inexperienced labor.

CONCRETE BLOCK MACHINE.
Machine closed, ready to receive material. with pallet board and locking arms in place, locked to top edge of rear side of moulding box.



CONCRETE BLOCK MACHINE.
Block released, ready to be removed.

VIEW IN ONE OF THE FAMOUS PORTLAND STONE QUARRIES, ISLE OF PORTLAND, DORSETSHIRE, ENGLAND.

From this natural stone—for centuries a favorite building stone for churches and public buildings in England—Portland cement derived its name. For a general view and description of the quarries, see frontispiece.

PORTLAND CEMENT WORKS OF ASPDIN, ORD & COMPANY AT GATESHEAD-ON-TYNE, ENGLAND.
These works, located on the bank of the river, opposite Newcastle, were in flourishing condition about 1852. View reproduced from an old print.

and the method of keeping out dampness, will vary with the conditions to be provided for. It is not always possible to remove water pressure from around foundation walls, or from beneath cellar floors, by a system of drains leading to a lower level, as often recommended; and even if this is possible, the presence of water around the porous material used in such places would indicate a possibility of absorption of dampness. Where water pressure is present, not only must the walls and floors be protected against the passage of water, but also against failure due to the existing hydraulic pressure.

As shown by Table XXI, dampness may be excluded from cellar walls and floors by the use of an enveloping layer of coal-tar pitch, asphalt, or some proprietary bituminous compound used with felt or burlap as a means of strength to the coating. This layer of damp-proofing material is carried in one continuous sheet under the foundation walls, and up on the outside of the structure to a point well above the line at which water is likely to exist. The number of ply of burlap or felt to be used has already been referred to.

In placing this membrane coating for preventing the absorption of water by the concrete, apply where practicable to exterior surfaces, or to the side from which the water comes. Remove all dirt and loose material before applying coating, and see that the concrete has set thoroughly before the coating is applied. The con-

crete surface should also be kept dry during the application of the materials for damp-proofing. Although the surface to which the coating is applied should be rough, it should not contain sharp points which may puncture the protecting material. Care should also be taken to see that all parts of the concrete which are in touch with the ground or with any source of possible dampness are completely covered by the enveloping coat.

In applying the cementing material, see that the pitch, asphalt, or other material covers all of the surface onto which it is spread, without cracks or blow-holes. The fabric should be rolled out smooth, and firmly pressed over the binding material so that it will stick firmly.

In breaking joints, allow at least 4 inches on cross-joints, and 12 inches on longitudinal joints. Laps of about 12 inches should be left where other work is to be joined. Where side walls are to be joined to floors, carry the side wall ends down over the floor layer, and allow about 24-inch lap. For joining roof and side walls in underground work, allow same lap in roof layers, and carry down on outside of wall layer.

For safety, protect the coating with a layer of mortar of 1 part Portland cement to 2 or 2½ parts sand. This coating varies in thickness from ¼ inch to 2 inches, according to the amount of wear which it is to receive or the degree of support to be furnished by the mortar coat. This mortar coat should be placed as soon as possible

after placing the waterproofing coat, so that a bond may be formed between it and the latter.

Where bricks or tile are used in place of the mortar coat, be very careful not to ram sharp corners into the waterproofing.

Figs. 14 and 16 show details of the method of applying a waterproofing or damp-proofing envelope to cellar floors and walls. The order of procedure is as follows: First, apply a course of waterproofing to the top of the footing as shown at **a** (Fig. 16), covering the entire top of the footing. Second, the foundation wall should now be erected, allowing a part of the waterproofing sheet already laid to project on each side of the wall. After the wall is completed and has set, turn the outer flap of the footing upward, and cement it firmly to the outside of the wall with asphalt or coal-tar pitch. Third, apply the type of coating necessary to the outside of the cellar wall, beginning at grade or above, and extending down and overlapping the turned-up part from the footing. This joint should be thoroughly made. Fourth, lay the rough concrete foundation for the cellar floor flush with the top of the footing, and place the layer of damp-proofing so that it overlaps the inner flap on the footing. As before, all joints should be made tight. On top of this waterproof or damp-proof coating on the cellar floor, place a thickness of either plain or reinforced concrete sufficient to withstand the existing water pressure, or to act as a wearing surface.

It is assumed in Figs. 15, 16, and 17, that sufficient space has been left temporarily around the foundation to allow for an excavation larger than that needed for the building proper, in order to allow room for workmen in applying the exterior coating to the walls. If it is not possible to provide this exterior space, the scheme shown in Fig. 20 may be resorted to. A thin curtain wall of lean concrete, or of one layer

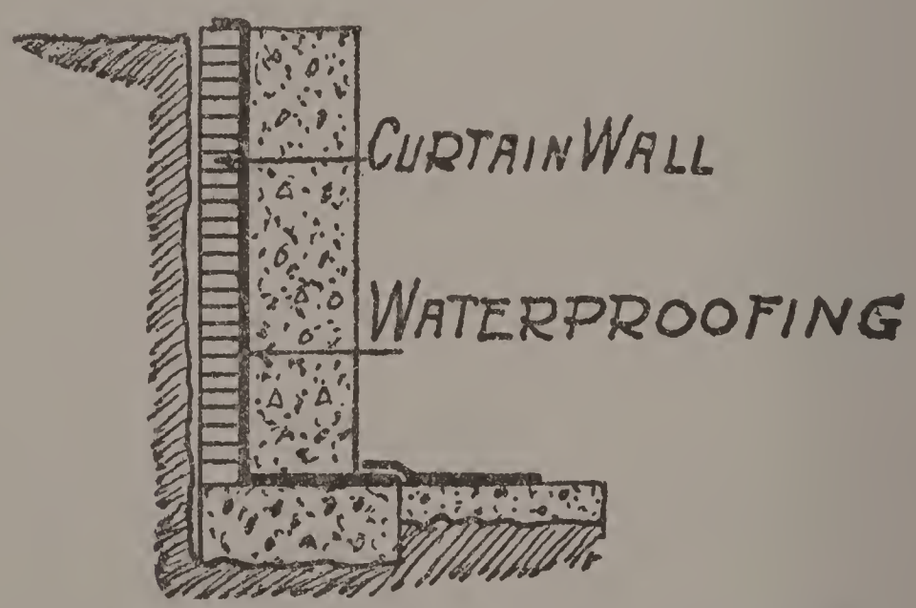


Fig. 20. Use of Curtain Wall in Close Quarters.

of brick may be used as a backing for the protective coating, and then the foundation proper cast directly against this waterproofing wall.

Concrete is by nature a porous material. Proper grading of cement and aggregates may produce a combination of such a nature that the material formed is proof against the actual passage of perceptible quantities of water from one part to another of the structure in which the material is used; but at the same time, dampness may exist to a greater or less extent throughout

the whole mass, and in adjacent parts of the structure which are connected to the part touching water, damp ground, or any source of dampness.

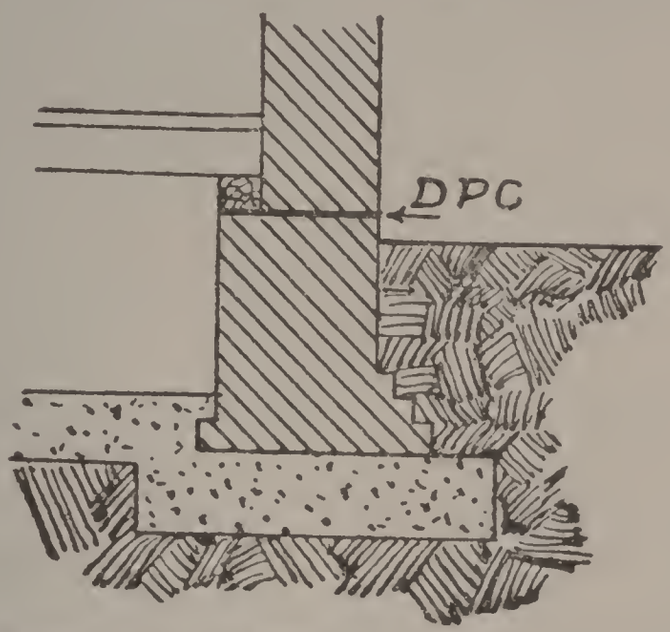


Fig. 20A. Method of Preventing Absorption from Foundation.

The above discussion of methods of waterproofing and damp-proofing cellars and cellar walls has been treated at considerable length, because we believe that it is of the utmost importance. A cellar wall which permits the entrance of water to a cellar, not only allows a damp cellar to exist, but also transmits dampness upward into other walls of a porous nature which rest upon this cellar wall. The existence of an actual head of water is not always necessary to produce this result. Where no cellar is used and the house is built directly upon a concrete foundation resting upon footings, a layer of sheet lead, pitch, or some damp-proofing medium, as shown in Fig. 20A, should be placed between the foundation walls and those of the building proper, to prevent dampness from

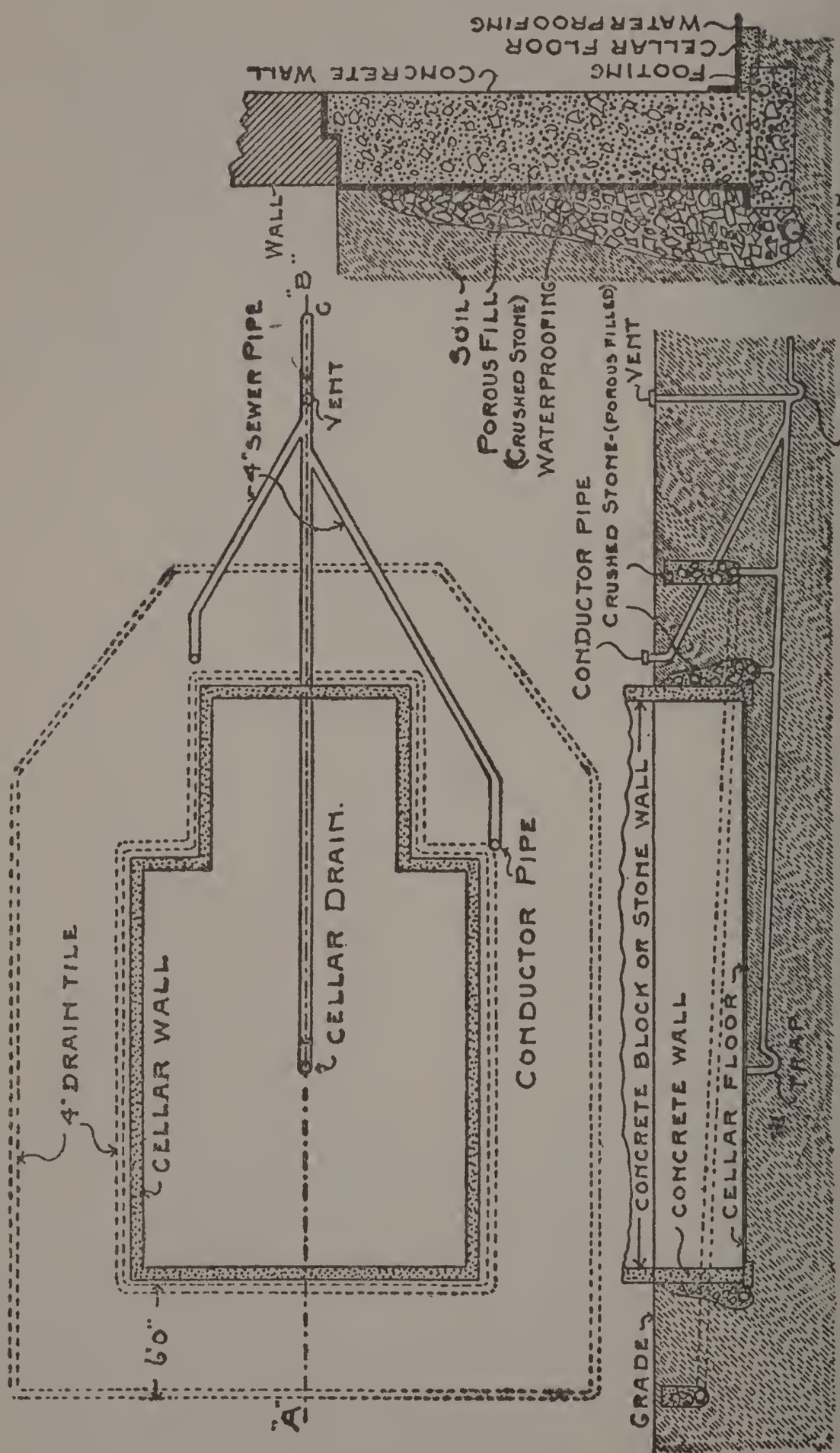


Fig. 20B. Plan and Sections of Waterproofed Cellar, Illustrating Use of Drainage Piping.

creeping upwards from the foundations. The space between the ground and the first floor of a dwelling of this type should be well ventilated by the use of protected openings through the foundation walls. These openings should be left in such walls that the prevailing winds of the locality will strike through them.

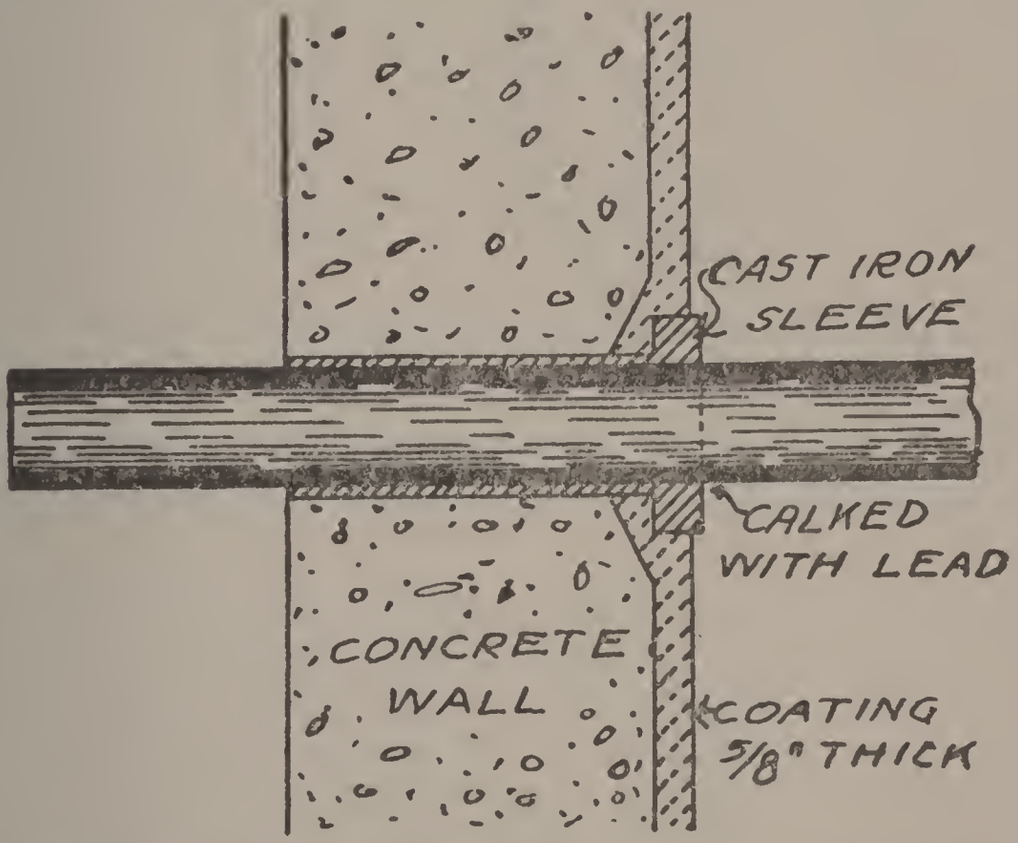


Fig. 20C. Protecting an Opening through a Concrete Wall.

Figs. 21 to 24 show methods of waterproofing bridge floors, subways, etc.

Now that we have provided against dampness arising from sources below grade line, let us see what can be done to protect the side walls and portions of the building above grade.

We have already stated that walls may be damp-proofed against the action of the elements by the use of special construction; by the use of

protective mediums in the form of water repellants, or substances which fill the pores of the concrete; or by a combination of the two methods.

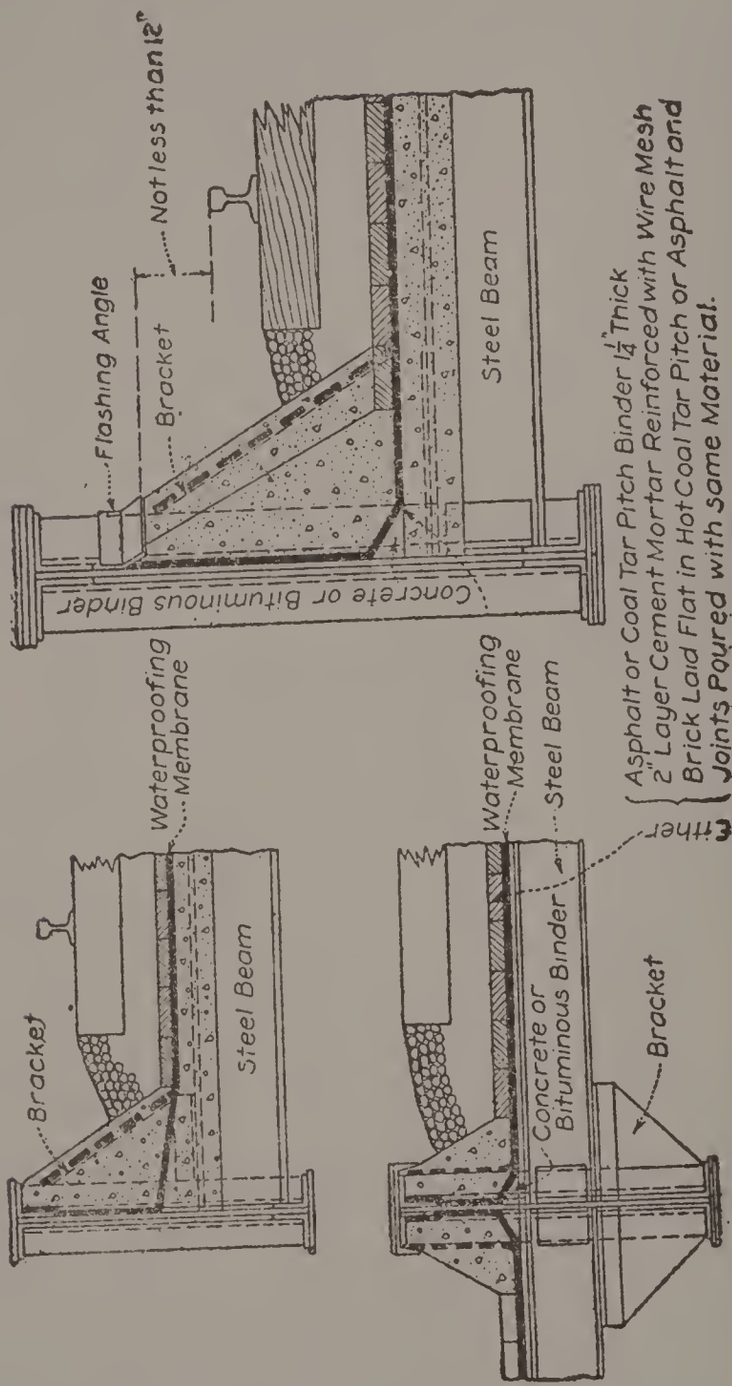


Fig. 21. Methods of Waterproofing Plate-Girder Bridge Floors.

Let us first see how the walls of a structure act in regard to the transmission of dampness. If we thoroughly wet one end of a piece of blotting paper, water will soon find its way along the

length of the piece, and, if not too large, the entire piece will become damp. If we were to wet a piece of blotting paper and place it in a

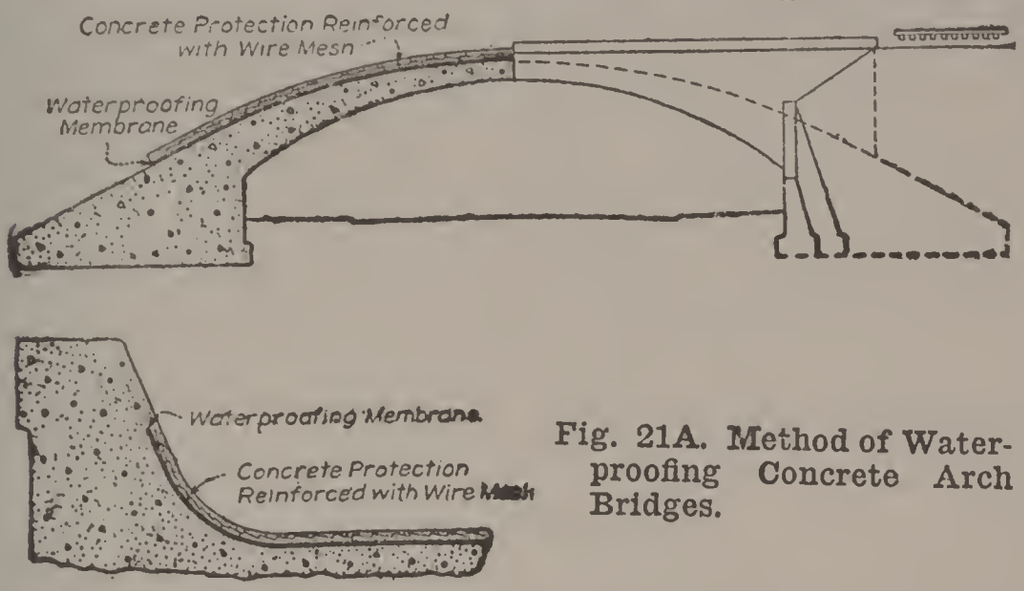

Concrete Protection Reinforced with Wire Mesh
Waterproofing Membrane
Waterproofing Membrane
Concrete Protection Reinforced with Wire Mesh

Fig. 21A. Method of Waterproofing Concrete Arch Bridges.

closed vessel with another dry piece, but not touching the latter, the dry piece would slowly take up moisture from the wet one. But if we

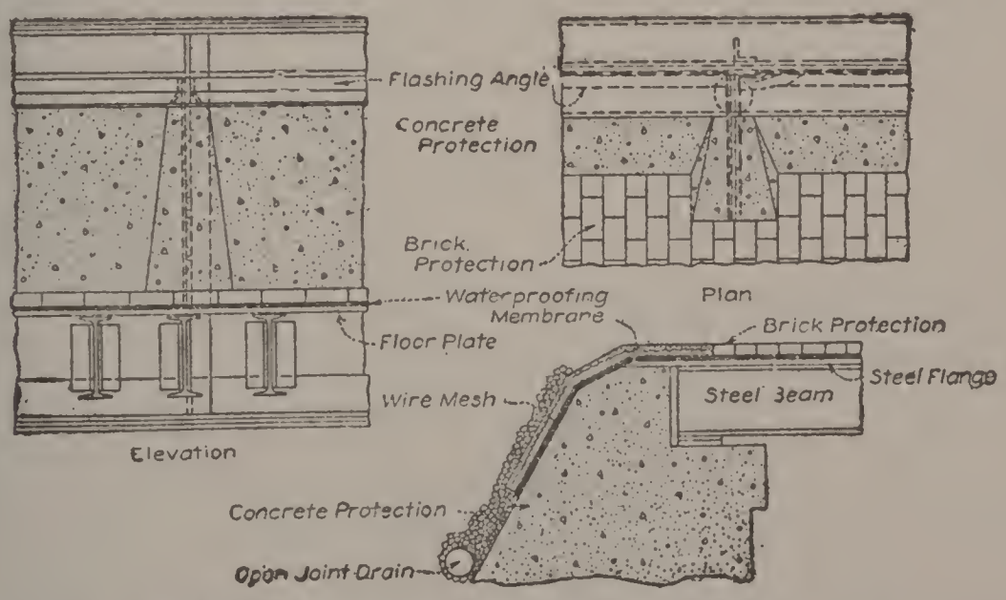


Fig. 22. Method of Waterproofing Steel-Beam Bridge Floors.

allow air to circulate freely through the vessel, the wet piece will become dry without appreciable change in the dry piece. Just so with a wall made up of materials such as are commonly used

in building, since these materials are either hygroscopic (moisture absorbent) or possess capillary attraction to some extent. A solid wall will transmit dampness; or a connecting link between two sections of such a wall, if it is of a material which will transmit moisture, will allow the same action to a modified extent. Two walls separated by a closed air-space would tend to carry dampness from one wall to the other; but a ventilated space between

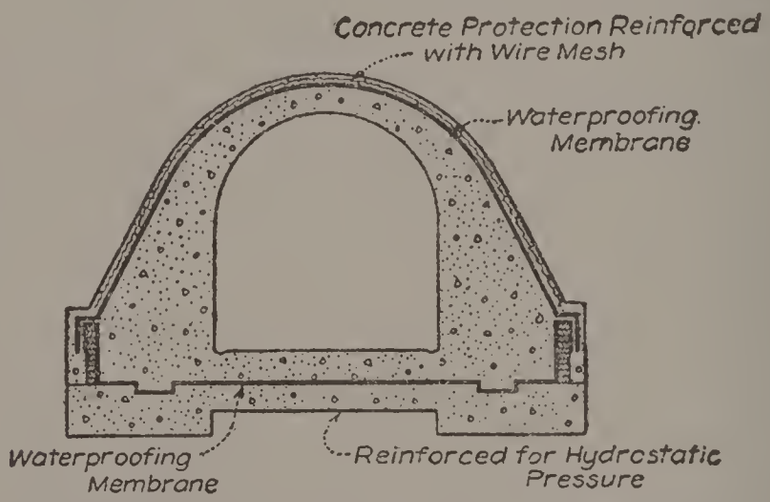


Fig. 23. Method of Waterproofing Concrete-Lined Subway.

the two walls, with no capillary bond between them, should allow a dry inner wall. This does not mean that a ventilating system is needed in the wall, or that openings are needed, of such a size that changes in temperature will be quickly transmitted to the inner walls. What is desired is to furnish only sufficient air to absorb and remove the moisture which collects. The removal of moisture in this manner should not be confounded with a method for drainage where needed.

Where metal bonds, or materials of any kind

which are liable to injury from water or dampness, are used in a hollow wall, care must be taken to coat these materials in such a manner that they will not be affected by the dampness.

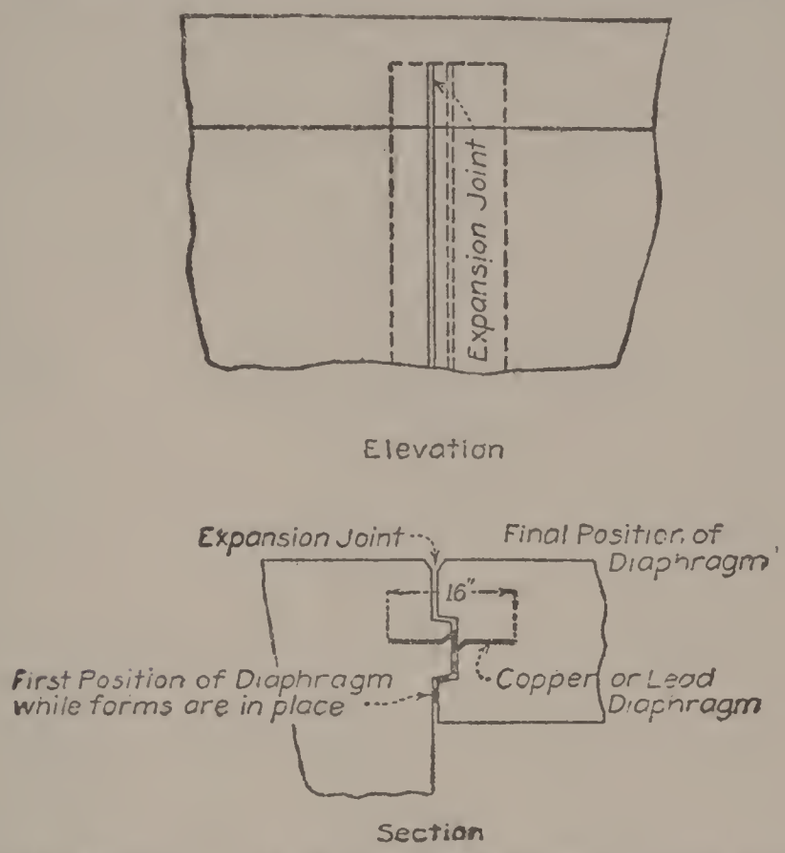


Fig. 24. Method of Waterproofing Expansion Joints.

Insurance engineers claim that passages in walls or between floors—when such passages connect with, or open into, other parts of a structure—are dangerous from the standpoint of rapid spread of fire to different parts of a structure. Their claim is founded upon the reasonable basis that where a circulation of air exists for ventilating purposes, a path is made for flame. For this reason it would seem that air-spaces which are left as a preventative against moisture passing through to the inner (or room) side of a wall, should be cut off from the interior

of the structure and receive their ventilation from the outside or in such manner that they will not permit the spread of fire. Types of hollow-wall construction of the block type are illustrated in Figs. 25, 50, and 51. With the help of special forms, monolithic walls can also be poured double, with intervening dead air space.

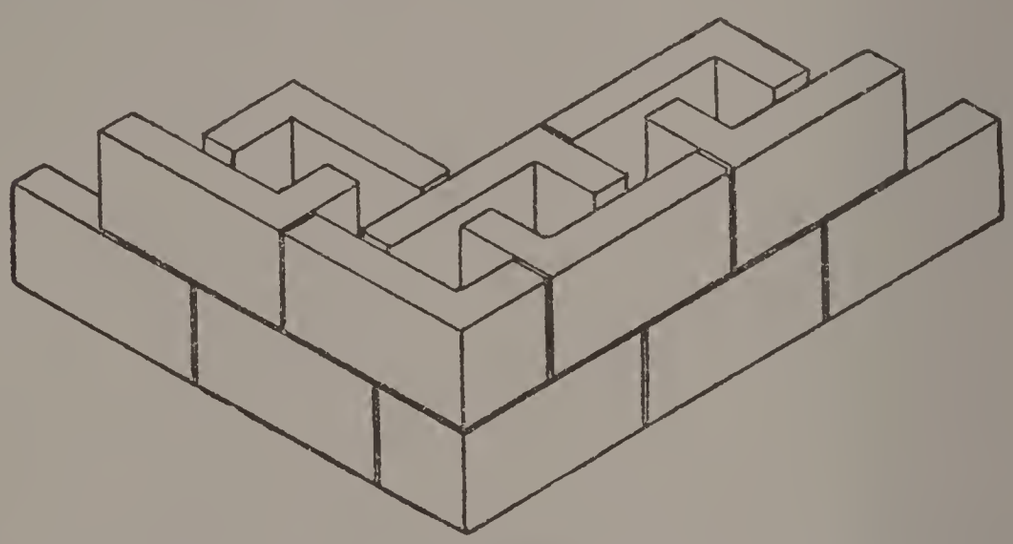


Fig. 25. Concrete Block Wall of Continuous Air-Space Type.

Where damp-proofing is to be provided by the use of a protective medium, the result may be accomplished by the use of coatings which are to be placed either on the exterior surface or on the interior surface of the wall. Many trade preparations for this purpose are on the market, some of them combining a color effect with their damp-proofing qualities. In addition to these trade preparations—which should always be used as directed by the manufacturers—Table XXI also shows methods of damp-proofing exterior walls, and presents details of application.

In applying surface coatings of this nature, care should be taken to see that the surfaces

treated are in a proper condition to receive the coating, and that the material is carefully applied. See that all surfaces are clean, free from

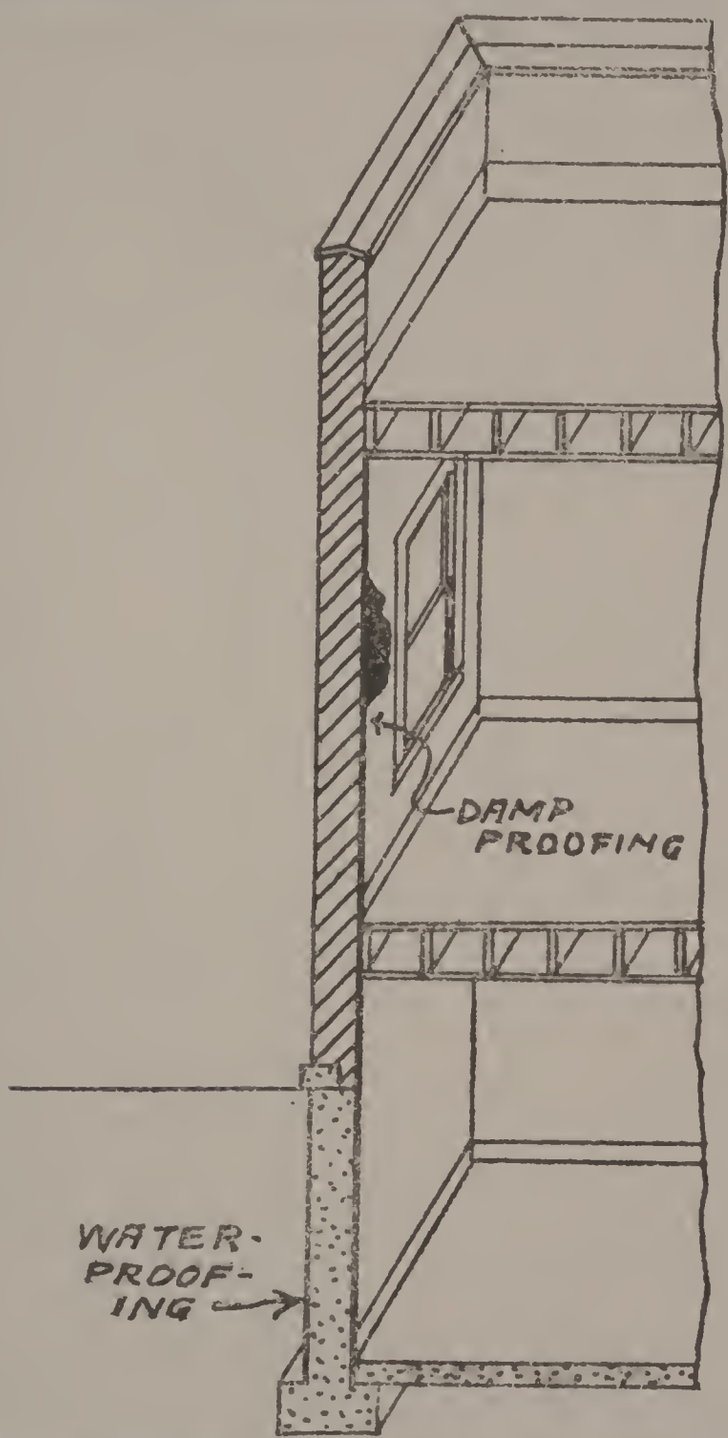


Fig. 26. Application of Damp-Proofing to Plastered Wall in Place of Furring and Lath.

loose material, and dry, in order that the coating material may sink into the concrete and fill the pores. Often one coat is not sufficient to do the

work properly, and a second or third coat is needed to follow up the first and properly fill the wall. A good rule to observe is to follow carefully the directions of the manufacturer in every case.

It may readily be seen that a compound which is applied to the exterior surface of a wall prevents the absorption of water into the wall, while a compound of an asphaltic or bituminous nature which is applied to the interior surface simply prevents the dampness from entering the rooms of the dwelling. Each type of compound has its advantages, since one prevents exterior discoloration after storms, and the other allows the interior plaster to be placed directly upon the wall, as shown in Fig. 26. This is made possible by the "tackiness" of the compound providing a substitute for lath and furring.

In stucco work, the integral method of waterproofing has been used with considerable success; but care should be taken to see that the hydrated lime or other compounds or liquid preparations which are used to fortify the wall against dampness are thoroughly mixed into the mortar. If stucco is not damp-proofed, there is a possibility of the penetration of dampness and a wasting away of the metal lath beneath the stucco.

During all of this discussion of damp-proofing, the fact must not be disregarded that a firm surface without cracks or openings is necessary for good results. The membrane method, when

used with felt or burlap reinforcement, will allow for slight cracks and imperfections in the surface to be covered, or will allow the formation of small cracks after placing; but the purpose of the integral method and the ordinary surface coating method is defeated as soon as an unprotected opening appears.

Provision against dampness from the roof of a dwelling built of concrete, is similar to that used in any other structure. If the roof itself is built of concrete, it may be made waterproof on the top surface by the use of any of the good ready roofing materials, laid as recommended by their makers. Tar and felt, or asphalt and felt, are materials that are used to a great extent.

Proper flashing should be provided around openings for skylights, ventilators, chimneys, and where roof joins parapet walls. Fig. 27 shows various methods of placing flashings. **A** illustrates a method in which a metal counter-flashing is used where it is not desired to carry the waterproofing layer through the parapet wall or up to the coping as shown in **B** and **C**. When the metal counter-flashing is used, the metal should start at about 12 inches from the roof surface, and extend down over the flashing to a point about 2 inches above the roof. The inner part of the parapet wall above the metal should be given a thorough coating of waterproofing, in order to prevent the penetration of dampness which might pass downward to the walls below. The method of protection shown in Fig. 27 (**B**)

Fig. 27. Methods of Arrangement of Flashings in Roof Protection.

WILLIAM ASPDIN.

A pioneer in the manufacture of Portland cement, who first developed the industry to a substantial commercial footing in England. He was a son of Joseph Aspdin, of Leeds, original inventor and patentee of Portland cement, but died at Holstein in what is now a part of the German Empire, during the Schleswig-Holstein War, in 1864, aged about 57 years. Portrait reproduced from an old tintype.

OLDEST EXAMPLE OF PORTLAND CEMENT ORNAMENTAL WORK.

How "Portland Hall," projected residence for William Aspdin, looks today. Structure in background, now used as a private residence, is the only portion of the "Hall" that was completed. In the foreground are shown some of the elaborate gate-posts, and a portion of the cement-stuccoed brick walls surrounding the grounds. Portland cement concrete.

CONCRETE MIXER OF CONTINUOUS TYPE, USED IN STREET-RAILWAY WORK.

GANG OF WORKMEN EXCAVATING FOR SIDEWALK.

would prevent this form of transmission of dampness.

Leaks around windows or other similar openings may be due to faulty design in the structure, or to careless handling of damp-proofing mediums when treating exposed surfaces. Likewise, the sweating of walls, as already referred to, may be controlled largely by the type of wall used. Such points as these may be safeguarded by proper design and good workmanship.

While the preceding paragraphs relate mainly to concrete construction, the reader must understand that other materials used for building purposes are susceptible to dampness, as well as concrete. Brick and stone work laid up with mortar joints have need of protection, and may be treated similarly to concrete, as shown by Table XXI. Thus it is hardly fair to use the grim specter of dampness as an argument against the use of concrete for dwellings. A home built of concrete blocks, of double walls with air-space, of stucco construction, or of solid mass work, if properly protected in building, and weather-proofed in thorough shape by the use of reliable mediums or compounds applied with judgment as to fitness and in a workmanlike manner, will give satisfaction to the owner, and a comfortable, dry, sanitary dwelling for the occupant.

Waterproofing Cement Stucco

Careful measurements reveal the fact that

cement, like wood, swells on wetting, and contracts on drying—this action being kept up even after the lapse of years. This has been demonstrated by experts of the United States Department of Agriculture and in the technical laboratories of the University of Michigan.

In some cases the amount of expansion (due to wetting) was as great as that due to 100 degrees' increase of temperature. This is a startling fact, when it is remembered that concrete expands with heat just as much as iron does. The strains due to wetting and drying are therefore very severe, and come quickly and repeatedly. It is not difficult to see why this should be a serious source of cracking.

It is fortunate that only the cement is affected, the sand remaining practically uninfluenced by moisture. Therefore lean mortars are much less affected than rich ones. A 1:3 stucco, when moistened, expands much less than a 1:2. But, as Prof. A. H. White, of the University of Michigan, says: "If a stucco is lean enough to avoid cracks, water will go through it freely; and if it is rich enough to keep out water, it will crack."

In Italy, where stuccos have been used for centuries, masonry walls were thick and waterproof in themselves. Cement was made from pulverized natural rock, and lean stucco mixtures were a matter of economy. The passage of ages has developed comparatively little checking in the Italian stuccos. But to-day, in

America, Portland cement is cheap, walls are thin, and climate is severe, so that rich mixtures have been used in the attempt to get cheap waterproofing. The result is excessive hair-cracking.

It is, of course, true that a 1:2 stucco is more waterproof than a 1:3, but it is very much more liable to crack. On the other hand, a 1:3 stucco, properly applied, is safe from cracking, though very porous. This, then, is the dilemma which confronts the constructor; how to make stucco lean enough to avoid cracks, yet non-porous enough to keep out water. The problem has been solved by the use of a 1:3 mortar in conjunction with an effective waterproofing compound.

The **leanness of the mortar** prevents cracks, and the **compound** makes the mortar waterproof. This gives dependable results, both as to permanency of surface and permanency of waterproofing. It is in every way more satisfactory than asbestos or patented stuccos, which do not positively prevent checking and are never entirely waterproof.

It must be emphasized that with a lean mortar the permanency of the waterproofing compound is a very important point, as the stucco is exposed to beating storms. That class of compound using stearates, oleates, or other soapy material as a base, gradually washes out under prolonged action of water, which slowly but surely dissolves even stearate of lime. A per-

manently waterproof stucco is dependent on using a compound that is absolutely insoluble and unaffected by the elements. Bituminous waterproofing products belong to this class; and compounds have been developed which are miscible with water, yet become absolutely insoluble after the mortar has set. This result is obtained by emulsifying the bitumen, which then mixes with water as easily as milk does (milk is an emulsion). But when the mortar sets, it de-emulsifies the bitumen, which then becomes as insoluble as a milk spot. (Butter is de-emulsified milk, and is not miscible with water.)

Bituminous materials so prepared give a very high degree of permanent waterproofing. They are unaffected by salt-air, brine, running water, boiling water, and ordinary chemicals. They also lubricate the mortar, enabling a very lean mixture to be troweled easily and compactly. Moreover, they retard the too rapid drying-out of the stucco.

If new, green stucco is subjected to the rapid evaporation of hot summer days, great care must be taken to prevent premature drying-out. For the setting of Portland cement is a chemical reaction that requires time and moisture. Mortar will have no strength unless this set is obtained. As mortar dries, it shrinks. This shrinking puts a strain on the mortar, which causes cracks if it comes before the cement has sufficient strength to withstand it. If, however, the stucco is kept moist for several days, by means of tarpaulins

or fine spray, the cement will harden normally and become strong enough to withstand the strain caused by drying. Soap compounds should be avoided, as they delay the setting, thus causing the mortar to remain weak for a longer time. If stucco is made from a lean mortar, properly waterproofed, properly foundationed, and kept from premature drying, it may be allowed to harden without fear of immediate or subsequent cracking.

On large surfaces the thermal expansion should be considered, especially if the stucco is applied to a base having a different rate of expansion. It may be advisable to divide the surface into panels, having projections which add to the pleasing effect and facilitate the uniform application of the stucco.

Making Concrete Acid-Proof

Experiments conducted by the Colorado Experiment Station, proved that vinegar (acetic acid) will act upon porous cement work. Leaks develop in unprotected cement cisterns used for vinegar and other acid fluids, and the vinegar turns black. This can easily be prevented by lining the cistern or tank with paraffine.

The process of lining a cement cistern with paraffine is so simple that anyone with ordinary ability can easily obtain the desired results. In case an old cement-lined cistern is to be coated with paraffine, it must first be cleaned thoroughly. Then it should be given at least two

coats of neat cement and water. The coats need not be applied more than 24 hours apart. The cistern is now ready for the paraffine coat.

The paraffine is heated by means of a small blow torch or gasoline stove until it is a very little above the melting point. It may then be applied to the inner surface of the cistern with a cloth or paint-brush. In case a cloth is to be used, the hand should be protected by a heavy leather glove. The paraffine should be put on in a thin layer and thoroughly rubbed while hot. It should not be rubbed after it starts to solidify. The operator must necessarily work rapidly in order to get the coating well rubbed before the paraffine begins to harden. The coating will not allow of bruising, and for this reason it is suggested that the bottom of the cistern be left until the last, and the work of coating be done from a suspended platform rather than from a ladder placed upon the bottom. Great care should be taken not to drop any objects upon the coated parts of the cistern.

In case a new cistern is to be made, the walls may be constructed of 1 part Portland cement to 4 parts clean, sharp sand. The walls should be made of a wet or "slush" mixture. They should be thick enough to insure against cracking.

Water-Glass

Water-glass is widely used for damp-proofing concrete surfaces, for preventing dusting of floors, etc. Probably most of the material sold

under this popular name is **sodium silicate**; but the name also includes silicate of potash, or compound derivatives of both silicate of soda and silicate of potash, or mixtures of both.

These silicates are prepared by melting together mixtures of quartz or white sand and soda ash or potash, as the case may be. These mixtures, when melted in proper proportions, form a glassy mass which is soluble in hot water.

The process of manufacture consists essentially in melting the above materials, usually in the presence of charcoal or other form of carbon, then pulverizing and leaching out the material with hot water. The silicate or water-glass is made of different strengths, and is sold according to percentage of dry silicate present in the solution, usually 33 to 66 per cent.

There is hardly any material that has caused the paint chemist more heartache than this very water-glass, for it seems to offer more advantages when used as a paint vehicle than any other material known to science. At first glance, it would appear to be ideal for paint purposes. First, because it would be a very cheap material. Secondly, when used in paint, it would make one which could be more readily applied. Third, it would dry quickly, and is entirely odorless and non-poisonous. Fourth, it would prevent the formation of mould or fungus. Fifth, it would also prevent worms or dry rot in wood; and lastly, it would be a fire-retardant and fireproof to a very large extent.

Naturally these apparent facts led the chemist to experiment along various lines in order to produce a paint from this material which would be practical. But when a great deal of time and worry has been expended on the material, it will be found more disadvantageous than advantageous, for the reason that it has heretofore been impossible to overcome the difficulties which beset this material. First of all, it is very unstable; that is, it will change in character from the slightest causes, and sometimes without any apparent cause. Second, it can be used only with a very limited number of pigments, because most of the pigments have some action on the water-glass, causing it usually to coagulate. Third, it does not remain smooth, but forms a slight efflorescence of white powder soda on the surface. Fourth, it has a tendency to chip, crack, or peel off. Fifth, atmospheric changes have a very deleterious effect on this material, as have also acids and gases of various kinds.

In mixing colors with water-glass, many changes take place. Sometimes the color changes entirely, due to the action of the alkali in the water-glass. Then, again, the color may act upon the silicate of soda or potash, forming therewith an insoluble silicate, such as lead silicate or zinc silicate, so that when the color is mixed with water-glass it immediately causes the entire mass to become solid instead of remaining in a paint consistency. As a matter of fact, most pigments act thus to some degree.

The lead compounds and zinc compounds have this action to a very marked degree, so that it takes place immediately. The iron oxides, ocher, and umbers work slowly; and a very few materials like chromium, barium chromate, ultramarine blue, and the graphite blacks work very slowly upon the water-glass, and can be mixed for some considerable time. Whiting and clay have a decided action upon this material. It will be seen, therefore, so far as the use of water-glass with pigments is concerned, it is almost impossible to make a mixture which will keep any length of time.

A number of attempts have been made to make use of water-glass by applying first the pigment bound with glue or some other material of a similar nature, and then applying over this material a solution of water-glass. This has a disadvantage in necessitating two operations; and it is also necessary to overcome the action of the water-glass on the colors, especially those colors that are readily affected by alkali.

Silicate of soda or water-glass is largely used for the purpose of fireproofing various materials. Wall-paper has been fireproofed by the use of water-glass; but precaution must be taken with regard to colors, as mentioned heretofore. Scenery and similar products have been treated with water-glass for the purpose of fireproofing.

Water-glass is a very useful material as a binding substance, and is used very largely in the manufacture of boiler coverings and all of

the asbestos products, as it acts as a fireproof glue for the purpose of binding the fine fibers together. It has also been used for mending various materials, and it is extremely useful for that purpose. It is also extensively used in the manufacture of artificial stone and similar substances.

As a fireproofing material, silicate of soda or water-glass is probably equal to any other substance used for that purpose. It has the disadvantage of being alkaline in its action and in its nature. It is always used thinned down with water, and should not be applied too heavily, otherwise it will only collect on the surface and flake off when dry.

Dusting of Floors. If dusting should occur where a concrete floor is used, it may be stopped—or prevented before its occurrence—by applying water-glass. The following method of procedure is recommended:

Wash the floor thoroughly with clear water, scrubbing with a stiff broom or scrubbing brush, removing all dirt; and allow the surface to dry. Mix 1 part water-glass (Sodium silicate) of 40 degrees Baumé, with 3 to 4 parts of water, total 4 to 5 parts, depending upon the porosity of the concrete. The denser the concrete, the weaker the solution required.

Apply with a brush one coat evenly over the entire surface. This will penetrate into the pores of the concrete. Allow the concrete surface to dry; and after 24 hours, apply another coat the same as before. Again allow the surface to dry, and apply another coat. If,

after 24 hours, the third coat is not flush with the surface in any part of the floor, apply another coat.

There are also on the market special preparations and compounds for the protective and decorative treatment of floors, which are said to give good satisfaction when used according to directions.

CONCRETE TROUBLES AND THEIR REMEDIES

For good results, concrete must be used correctly. Big work, or work requiring engineering skill, should be left to the engineer; but ordinary small work, such as stucco, block work, sidewalks, small tanks, foundations, silos, etc., can be carried on successfully by any intelligent workman who is familiar with the general handling of building materials, and who will read the current cement literature issued by magazine publishers and by the cement companies.

The following paragraphs tell of some of the troubles met with by the inexperienced worker. While it should be noted that defects in materials, especially aggregates, are to be watched, the greater number of troubles come either from poor design or from poor handling and construction.

Troubles Due to Poor Materials

Cement. Be sure that the cement is obtained from a reliable manufacturer. In the manufac-

ture of "standard" Portland cement in all well-equipped plants in the United States, so careful is the technical supervision exercised over every process of the selection, proportioning, and manipulation of the raw materials, that the liability to imperfect work resulting from poor quality in the finished product is practically negligible. The cement, however, will be injured during storage and before finally entering the mixture, if moisture is allowed to attack it. Accordingly, avoid using cement which has been wet and which contains lumps that cannot be pulverized with the hands.

Sand or Fine Aggregate. Fine sand or stone dust may be a reason for poor concrete. It is shown that a sand which consists of particles well graded in size from coarse to fine will produce a stronger mortar than will a sand whose particles are fine and nearly all of the same size. This point is often overlooked, and a mixture of 1 part Portland cement to 3 parts sand used when a 1 to 2 mixture is really needed. A 1 to 3 mixture of cement and well-graded sand will be as strong as a 1 to 2 mixture using fine sand.

Dirty sand, or sand containing loam or vegetable matter, usually causes trouble. A coating of clay on the particles of sand may prevent the contact of the sand and cement, thus destroying the bond which produces the true strength of the mixture. Particles of mica in the sand are also objectionable. Loam or vegetable matter

in the sand may either ruin or delay the hardening of the cement, thus causing failure through lack of strength.

The remedy in the above cases is apparent. Use a clean, well-graded sand which is free from all impurities. If the sand contains gravel, screen out the gravel on a ¼-inch screen, and use the screenings only as fine aggregate. Particles over ¼ inch in size should be classed as coarse aggregate. Sand containing dirt of any kind should generally be washed thoroughly before using, though a small percentage of clay (2 to 5 per cent) may be allowed, provided it does not form a coating around the sand grains. Limestone screenings often contain large proportions of fine, chalky dust, and this is responsible for a large share of defective concrete work.

Coarse Aggregate. Soft or rotten stone will cause disintegration in concrete, or allow excessive wear to occur. A hard grade of stone should be used. The following list gives the common materials used for the large aggregate. The relative value of each for concrete work is indicated by its position on the list: Trap rock, quartz, gravel, hard limestone, granite, marble, soft limestone, slag, sandstone, slate, and cinders.

If sand is used with crushed stone in the ordinary proportions, the crushed stone must be screened and free from dust. All particles which will pass a ¼-inch-mesh screen may be mixed with the sand and used as part of the fine

aggregate. Otherwise the balance of the mixture of coarse and fine aggregate will be disturbed, and a weak grade of concrete may result. For ordinary, plain, heavy work, stone which will pass a 2½-inch ring is taken as a maximum size; but for walls 12 inches thick and under, and for reinforced work, rock which will pass a 1-inch or a ¾-inch ring is given as a maximum size.

Troubles Due to Poor Design

Lack of Knowledge. Probably one of the most frequent causes of trouble in concrete work, both plain and reinforced, is the lack of true knowledge in regard to the working possibilities of the material. Too many ignore the results of years of practice and investigation by men of experience, and do things "the way that Bill Jenkins did on that Brown job." Bill may have been born under a lucky star; and then, again, he may have his "coming to him" yet.

Our advice is to learn the principles of concrete design before dabbling in it. Have some good reason for dimensioning your concrete as recommended in your plans or layout, and be sure that your reasons are based upon recognized practice. **Don't guess!**

A result of lack of knowledge of the fundamental principles of design is shown in cracked beams or floors due to too heavy loading, too little reinforcement, poorly arranged reinforce-

ment, improperly designed forms, insufficient foundations or supports for the forms, and many other equally important features.

Cracks from Settling. We speak of this one point, as we hear of instances of the kind quite often. The inexperienced builder will often erect a concrete block or stucco building, and, after a few months or after a winter has passed, will find that large cracks have developed in his walls. He may attempt to plaster these up, only to find that they have opened up again after a time. Then he condemns concrete and wants to know what to do. The answer is that it is really too late to do anything at this time. Possibly the cracks will remain at a permanent width after the house has shifted all that the foundation will allow. Then they may be mortar-filled with a greater or less degree of permanency.

The remedy—or really the preventative, in this case—is to construct the preliminary footings and foundations for this building of sufficient size to carry with safety the load which is to be placed upon them. Get down below the frost line, and avoid soft or unstable ground which may squeeze out from under any part of the footings, thereby allowing that part of the footing to sink. The wall will try to follow the sinking foundation, and a crack will result. Upheaval by frost will produce a similar result. Remember that concrete weighs about 150 pounds per cubic foot, and lumber weighs only

about 36 pounds for the same amount. Thus it will be seen that footings and foundations which will carry a frame structure safely may not be of sufficient size to carry a structure of the same dimensions when built of concrete. Besides, when not strongly built, timber framing will give to some extent with the movement of the building, whereas concrete will crack under such strains.

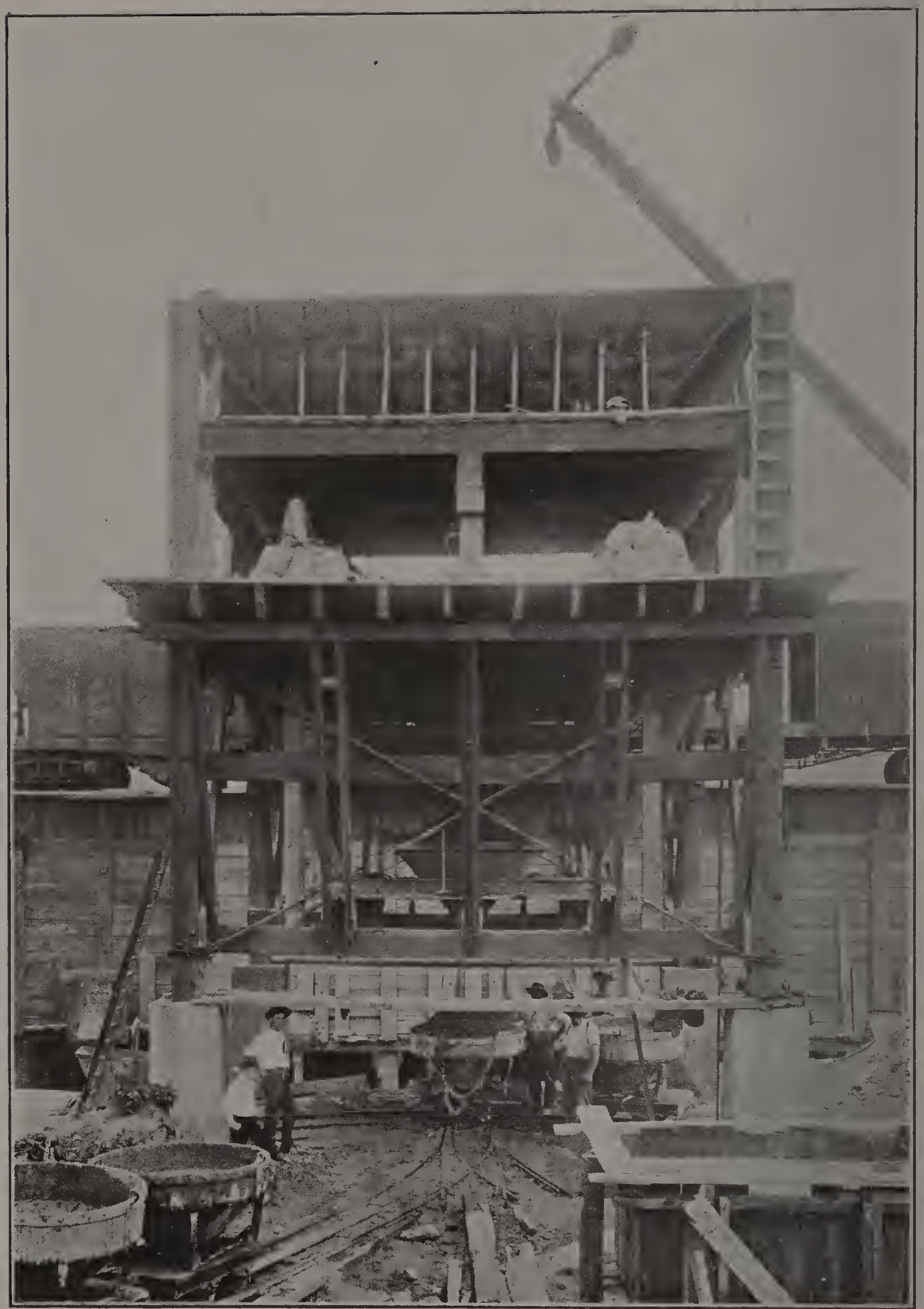
Similar care should be taken in preparing the bed for concrete floors, sidewalks, and pavements, so that cracks may not form as a result of the sinking of foundations.

Shrinkage and Expansion. The designer often neglects to provide for stresses in the concrete due to shrinkage or expansion. The result of this neglect may be the formation of cracks at definite locations in a big surface area, or at certain intervals in a long wall. Such cracks may not unlikely be due to the shrinkage stresses which are set up in the concrete when it hardens. Often cracks are seen that extend across a concrete pavement or sidewalk which has not been properly safeguarded when laid. Again, cracks may be found in floor-slabs which were cast at the same time that the walls surrounding them were placed. In many cases the slab may have cracked entirely away from the walls, and a seam will show around the entire slab.

Long concrete members will expand with a rise in temperature of the surrounding air or

CONCRETE FOUNDATION WORK FOR A LARGE HOTEL IN TOLEDO, OHIO.

Mixer on elevated platform with inclined chute for delivery of concrete to forms for footings.



CONCRETE MIXER OF GRAVITY TYPE.

Operates automatically. Consists essentially of a series of stationary hoppers of suitable proportions and pitch, mounted one above another on platforms. The aggregates, thoroughly wet, are drawn downward by gravity, passing through the dry cement and becoming coated with cement paste. The action of the successive hoppers imparts rotation to the mass, somewhat after the manner of the hour glass, in which, as is well known, the sand near the bottom comes out, in the hopper below, near the top.

SHEET-IRON KILN FOR HEATING SAND AND CEMENT FOR MORTAR.

ILLUSTRATING USE OF VARIOUS CONCRETING HAND-TOOLS.

1—Jointer; 2—Edger (⅜-in. radius); 5—Jointer; 6—Corner Tool; 8—Gutter Tool; 12—Raised (Tuck) Pointer; 15—Indentation Roller; 16—Driveway Roller; 17—Square Edger; 19—Driveway Groover; 20—Line Roller; 23—Radius Tool; 26—Curb-Gutter Tool; 27—Jointer; 30—Line Roller; 40—Bevel Edger; 44—Corrugating Tool; 48—Roller Jointer; 52—Aluminum Float, Smooth-Face; 59—Aluminum Float, Corrugated; 100—Curbing Edger.

from the effects of heat from the sun. If the member tends to grow longer, either something must give way at one end or the member will buckle up at some place in its length. This trouble is often found in the case of long sidewalks. When the member cools down again, it will contract, or at least try to. If the resistance to contraction—such as the friction of a slab on the ground—is greater than the tensile strength of the concrete, the concrete will break, and a localized crack in the surface will be the result.

The remedy for cracks due to expansion or contraction is either to reinforce the concrete thoroughly with steel in two directions, or to divide the work into small members. The steel prevents any local action from occurring at a given point, by distributing the shrinkage stresses evenly throughout the slab. Minute cracks may exist in the concrete itself, but they will be so fine and so close together that they cannot be found.

When concrete slabs or walls are divided into short lengths, each length will have only itself to look after, and may come and go with freedom so far as its neighbor is concerned. Care should be taken to see that a distinct, clear joint is left between parts and extending completely through the slab or member. This joint not only allows each of the parts to pull along easily when it shrinks, but also allows a little leeway for it to stretch without crowding its neighbor when it

expands from the action of heat. Sidewalk slabs will not rise from expansion or crack from settling or shrinkage when this precaution is taken.

In massive or heavy work which is not protected by shrinkage reinforcement, clear joints should be left every 50 feet of length of concrete member. If the work is of the nature of a light or thin wall, a joint should be left every 25 feet of length. In sidewalk work, it is commonly specified that no slab shall contain more than 36 square feet of top surface, nor have any length greater than 6 feet, though the specifications of the National Association of Cement Users allow 100 sq. ft. and 10 feet, respectively. In cement stucco work, the panel sizes are not large, and the concrete is thoroughly reinforced by the metal lath used in the construction.

Where a long concrete member butts directly against a crosswise member, expansion in the long member may cause failure by pushing outward on the cross member. The remedy in this case is either to leave ample joints all along the length of the pushing member, or to allow this member to extend through the crosswise member, with a clean-cut joint on each side of the union.

Faults of Construction

Forms. Irregularly shaped or bulged surfaces and members, or wavy lines on concrete members, may be due to poorly built or weakly

supported forms into which the concrete is poured. Insuring the necessary strength is the only remedy for this condition.

Rough surfaces which show ridges or other imperfections may be avoided by using planed lumber, and by taking care to make good joints when setting up forms. Light stock should not be used to support heavy loads of concrete, where a 2-inch plank would produce better strength and rigidity of outline. Careful form making is the carpenter's job, and, where extensive work is carried on, should be under the supervision of a competent man. A failure in form work before the concrete has thoroughly set, probably means a failure in the concrete itself.

Marred or roughened surfaces may also result from the use of dirty forms, or from forms which have not been properly oiled or wet before use. All forms should be washed or scraped free from any particles of concrete which may stick to them, before using a second time. Where forms are to remain in place for several weeks, oiling may not be necessary in the case of timber forms; but metal forms should always be oiled before using.

Crude oil is a good material for use on forms. A mixture of equal parts of boiled linseed oil and kerosene is also good. The object is to fill the pores of the wood and prevent absorption of moisture from the concrete, thus preventing a honeycombing action on the surface. The oil

should be applied each time the forms are used. Soft soap, and soap and water, are often used with good results on timber forms. It is claimed that the grease from a piece of fat salt pork will prevent concrete from sticking to metal forms, even when other oils fail. Water should not be used on timber forms during freezing weather.

Where corners or edges of concrete work break away on removal of forms, look for lack of clearance in the form which is pulled away from the broken part. It is often advisable to round off sharp edges by nailing small triangular strips of wood or leather fillet material into the forms before placing the concrete, where the importance of the work will warrant such care. Such a procedure, however, is not customary.

Mottled Surfaces. The mottled appearance often seen in concrete work may be due to a combination of different mixtures or grades of concrete, different kinds of sand or cement used in the same piece of work, poor mixing, separation of materials when placing, different degrees of wetness of mixture, different rates of drying-out of various parts of a structure, leaking-away of liquid concrete through loosely joined forms, and to other faults of construction which may be summed up under the heading of non-uniformity. The mottled appearance may be aggravated during damp or wet weather, due to absorption of water or moisture, unless the concrete is of a quality dense and impermeable.

The remedy for mottled surfaces is care in choosing and using materials. All materials should be of the same lot, mixed in the same proportions, and of the same degree of wetness, and should be used as nearly as possible without interruption of the concreting process. Work joined at two different dates may not bear the same appearance, since the conditions may not be the same at each time of placing. Poor mixing of materials may result in a streaky appearance in the work, due to the successive layers of concrete being of different proportions. Hand-mixed concrete should be turned over and over until a uniform color and quality of product result. The sand and cement should be thoroughly mixed when dry, then the stone added, and the complete mixture turned over at least three times, wet, with shovels. Machine-mixed concrete should have an amount of mixing equivalent to at least twenty turns in a batch mixer.

Rough patches showing exposed aggregate on the surface of concrete work may be due to too dry a mixture, to leaky forms from which the liquid concrete has run out and left the stone, to lack of spading or tamping, or to the ingredients of the concrete having separated as a result of dumping through too great a distance into the forms, or transporting too great a distance from mixer without remixing in barrow. The remedy for such defects is apparent.

Different times of drying out, or different methods of protection during the hardening

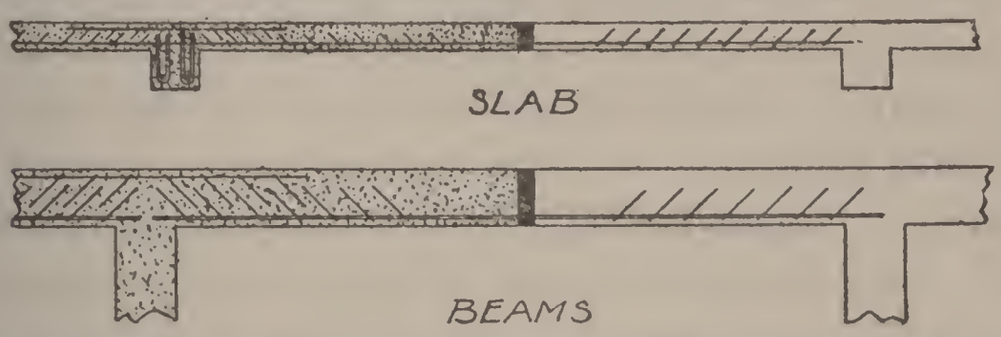
period, may cause differences in color of concrete surfaces. Rapid drying out may give the concrete a dead appearance, besides reducing strength; while the other extreme, where damp sand is used to protect the surface of a concrete slab, may cause the concrete to bleach to a slight extent. All concrete should be kept moist while hardening after it has taken on its initial set. Little difficulty in this feature is met with in damp weather; but in hot weather, frequent sprinkling, or covering of surfaces to protect them from the sun and wind, is necessary. Slight sprinkling and rapid drying out in spots will cause unsightly variation in color.

A good precaution to take where perfect, smooth surfaces without exposed aggregate are wanted, is to run a thin spade or a spade of special design down between the surface form and the concrete mass, to force back the larger particles of aggregate. Sometimes the desired effect is produced by placing a special surface layer of concrete or mortar in the forms in front of the main body, and tamping the backing well up against this extra coat. The latter method, however, is difficult and sometimes impracticable.

Cracks between Successive Days' Work. Cracks may be prevented between batches of concrete which are put in place on successive days, by cleaning the surface of the old concrete that is to be covered, removing all deposits on the face of the work, roughening the old sur-

face, and, after removing all loose particles of material, painting the joint with a neat cement grout, and then depositing the new concrete.

In reinforced concrete work, joints should be located at places where the shearing action is small and where plenty of steel reinforcement will tie the two lots of concrete together. Then the stresses at the joint should be such that the crack will tend to close when load is placed upon the member. Joints in columns may be made flush with the lower side of girders; and



Figs. 33 and 34. Location of Joints (shown by heavy black, upright lines) for Stopping Work during Slab and Beam Construction.

joints in the beams, girders, and slabs of a floor system should be made at or near the center of the span. In all cases, joints shall be made smooth, plane, and at right angles to the surfaces in which they exist.

Joining Old and New Concrete. Where concrete has dried out and thoroughly hardened, and new material is to be joined, it is difficult to obtain a satisfactory bond where bending or shearing action exists. In many instances, however, a good joint can be made in a manner similar to that described above for bonding succes-

sive days' work. Care should be taken to wet down the old concrete thoroughly before applying the cement grout coating.

Disintegrating. Disintegrating, or breaking up into small particles, or a constant dropping-away of small pieces of concrete from the main body, is often a source of trouble in various forms of concrete work. This defect may be due to a variety of causes. A lean mixture, too dry a mixture, imperfect mixing, or, as in many cases, poor aggregate, may be the cause of the trouble. There is a possibility that it is due to the action of some external agent which has come in contact with the cement before it has hardened properly.

The effect of frost on new concrete is to delay the hardening, and cause failure through lack of strength in the concrete when the load is applied or when the forms are removed, and in some cases to ruin the concrete. The remedy in this case is to heat the aggregate used, or the water; and then protect the new concrete by covering it with boards placed about 4 inches from the concrete surface. Over the boards, place tar paper or canvas tarpaulins, and bring the edges down so as to enclose the space created. Cover the top of the canvas or paper with hay, straw, or manure. When heat can be applied to the under surface of concrete work, a curtained space should be formed, and heated by means of salamanders burning coke, or, better still, with steam.

The effect of freezing is to cause the outer surface of the concrete to rough up and spall. Alternate freezing and thawing may produce bad results, owing to the interrupted setting of different parts of the mass. Where opportunity is given for concrete to harden under favorable conditions for 48 hours, and then freezing occurs, no bad results may follow if it is allowed properly to complete its hardening at some future time. No load should be placed upon the concrete during this period, and forms should be left in place until the mass has taken on its required strength.

Acids will affect new concrete or concrete which is of a porous nature. Concrete which is to be subjected to the action of dilute or weak acids should be composed of a very dense mixture of carefully graded materials, and should have obtained its full degree of hardness before exposure to the action of the acid.

Alkali earth is also claimed to injure and disintegrate concrete. As in the case of acids, a rich, dense, carefully graded mixture should be used, so as to prevent the absorption of alkaline water into the interior of the concrete.

Sea water is claimed by many to cause a breaking-down of the concrete structure. A gradual flaking-off of concrete particles may be observed in many cases. The remedy for this form of disintegration is to use a very dense mixture of concrete, and to keep the sea water away from the new concrete just as long as pos-

sible. Sand containing a large proportion of fine grains must not be used in this concrete.

Efflorescence. Complaint is often made in regard to the appearing of a whitish coating on cement work. This may show up only at joints between successive layers of concrete, or may come out in patches all over a surface. This disfiguration may sometimes be due either to the use of too wet a mixture, so that a part of the cement is floated to the surface of the work and there deposited, or to the fact that certain parts of the cement may not have been acted upon chemically by the water. These fine particles may lie within the mixture of concrete, and gradually work their way to the outside every time the concrete is subjected to a thorough wetting. In the majority of cases, however, the appearance of a scum on the surface of concrete work may be merely a concomitant of porosity in the concrete, being caused by the concrete soaking up water which is subsequently evaporated out by the sun or exterior heat. This water has the ability to dissolve what little soluble material may be in the cement or that occurring in the aggregate; and when brought to the surface, the water is evaporated, leaving a whitish deposit.

If the concrete is properly made—that is, constructed according to the best practice, using proper materials, and proper proportions—it will be so dense that there will be practically no absorption and consequently no efflorescence.

The preventative of this trouble, accordingly, lies in the use of an impermeable concrete made by using mixtures not leaner than 1:2:4 with ordinary aggregates, thoroughly mixed to a plastic consistency such that when piled in a heap it will settle to a rounded mass without flowing. Where rain water or surface water is to be contended with, the first requisite in designing a structure that is to be water-tight is to get rid of the water as directly and quickly as possible.

Dusting. Dusting or wearing away of concrete may be due to a poor mixture of materials, or to some disturbance in the setting of the mixture, such as freezing or too rapid drying out. In floors or other places where great wear occurs, a rich, dense mixture should be used for the wearing coat. The use of fine sand should never be permitted; aggregates containing particles up to ⅜-inch size are found to produce excellent wearing surfaces. The proportions of this top coating will vary from 1 part cement and 1½ parts sand or fine stone, to a 1:2 mixture.

To protect the work from too rapid drying out, it should be covered with damp sand, or protected from the wind and sun by means of wet canvas, burlap, blankets, etc., until the concrete has hardened. Then the surface should be sprinkled frequently for a period of 10 days, to allow the cement to set properly. Nothing should be allowed to touch the surface of the green concrete until it has set sufficiently to prevent disfiguration.

Water-glass has been successfully used to prevent dusting from concrete floors. It is applied in the manner described above on page 250.

Hair-Cracking. Many a good job of concreting has been disfigured by the appearance of fine hair-line cracks spread over the finished surface. This defect may be due to too much troweling of the finished surface, to too rapid drying-out of the concrete, or to the use of too rich a mixture of cement mortar. It is sometimes also caused by using an unsuitable sand.

The prevention of this trouble consists in using a mortar varying from 1:1½ to 1:2 parts of cement and sand for finishing coatings. This mixture should be troweled as little as possible, and preferably floated to a smooth surface with a wood float. This prevents bringing the finer particles of cement and sand to the surface, where they may form a film and crack in hardening. After troweling or floating, all work should be protected from rapid drying out for a week, if possible, by the use of wet covers as previously described.

Shelling or Spalling of Surface. Complaints are often made in regard to the shelling-off of finishing coats which are placed on floors, sidewalks, or plastered walls. The thin layer of concrete breaks up, comes off in patches, and seems to resist all attempts at repairs.

The cause of this defect is probably due to the improper placing of a layer of new con-

crete on a body of mortar or concrete which has already hardened. Bond of this type is difficult to make, and should be carefully treated. The best way is to avoid the need of such construction by placing the finishing coat at the same time that the body of concrete which is to be covered is laid. The finishing coat then is carried on while the concrete under it is still green, and a perfect bond results. A coat of this nature should never be less than ½ inch in thickness, and may be 1½ inches where heavy wear is to be resisted, as at crossings or driveways.

It is often claimed that the thickness of a coating which is to be placed on old work that has hardened should be sufficient to give the coating considerable strength in itself. From 2 to 3 inches is often recommended. Where this form of surface construction is attempted, the rule for joining old and new concrete given above should be carefully followed.

Where cement plaster is to be applied to masonry walls, a mechanical bond should be provided by raking out the joints between the brick or stone to a depth of ½ inch or more. The old surface should be thoroughly cleaned, preferably by chipping off the face of the brick or masonry wall; and the surface should be thoroughly wetted down to prevent it from absorbing water from the plaster coat, as otherwise the cement in the plaster will not be thoroughly hydrated and cannot possibly develop its full bonding strength. The utmost precaution

should be taken to prevent seepage of water into the masonry back of the plastered coating. To this end, all projecting courses should be protected by a thick layer of dense mortar troweled smooth and sloped to an angle sufficient to carry off water readily. Leaks in the wall where seepage is taking place may be discovered by sopping up the moisture with a sponge. These leaks must be either plugged or tapped before plastering is attempted.

Tools and Machinery for Concrete Work

With the skill and ingenuity characteristic of American enterprise in general, designers and inventors have developed a great variety of special tools, machines, and devices for accomplishing the different operations necessary in the mixing, handling, and working of concrete. In addition to numerous hand-operated tools, the list includes crushers and grinders; screens and separators; mixers; automatic measuring devices for water, cement, and aggregates; automatic and pneumatic tampers; engines for power; hoists; elevators; wheelbarrows; dump buckets and cars; machines for making blocks, sills, posts, brick, tile, shingles, etc. Many typical examples of these tools and machines are illustrated in various figures and plates throughout this volume.

SELECTION OF EQUIPMENT

The selection of the equipment necessary will depend on considerations of economy and efficiency; and these, in turn, will be found to depend on the size of the job, on the quantity to be mixed per day, and on local conditions peculiar to the work in hand. Each job, particularly on large work, constitutes a problem by itself, calling for careful analysis of details.

In general, it may be said that the plant should be located as near as possible to the place of depositing the concrete; uninterrupted facilities for handling materials, charging mixers, and distributing the concrete should be provided; the cycle of operations should be simplified as much as possible, and systematically maintained; machine parts should in all cases be capable of ready duplication to prevent delays from break-downs or wearing-out of parts; a plant should be adapted not only to the original job for which it is selected, but to subsequent work of other kinds; and, on small jobs, to depend on hand labor is usually more economical than to invest large sums in machinery.

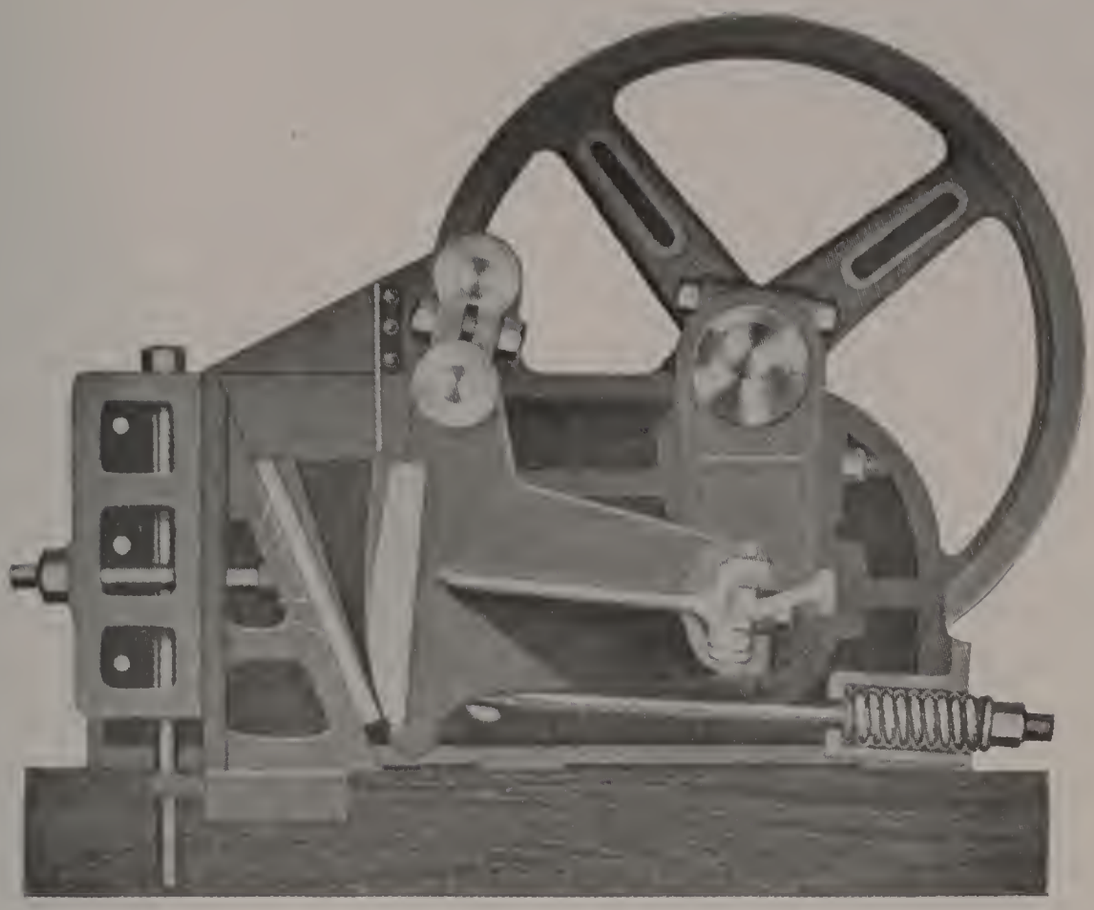
Generally speaking, there are three conditions which govern largely the nature and equipment of a concrete construction plant:

(a) The nature of the work for which concrete is desired.

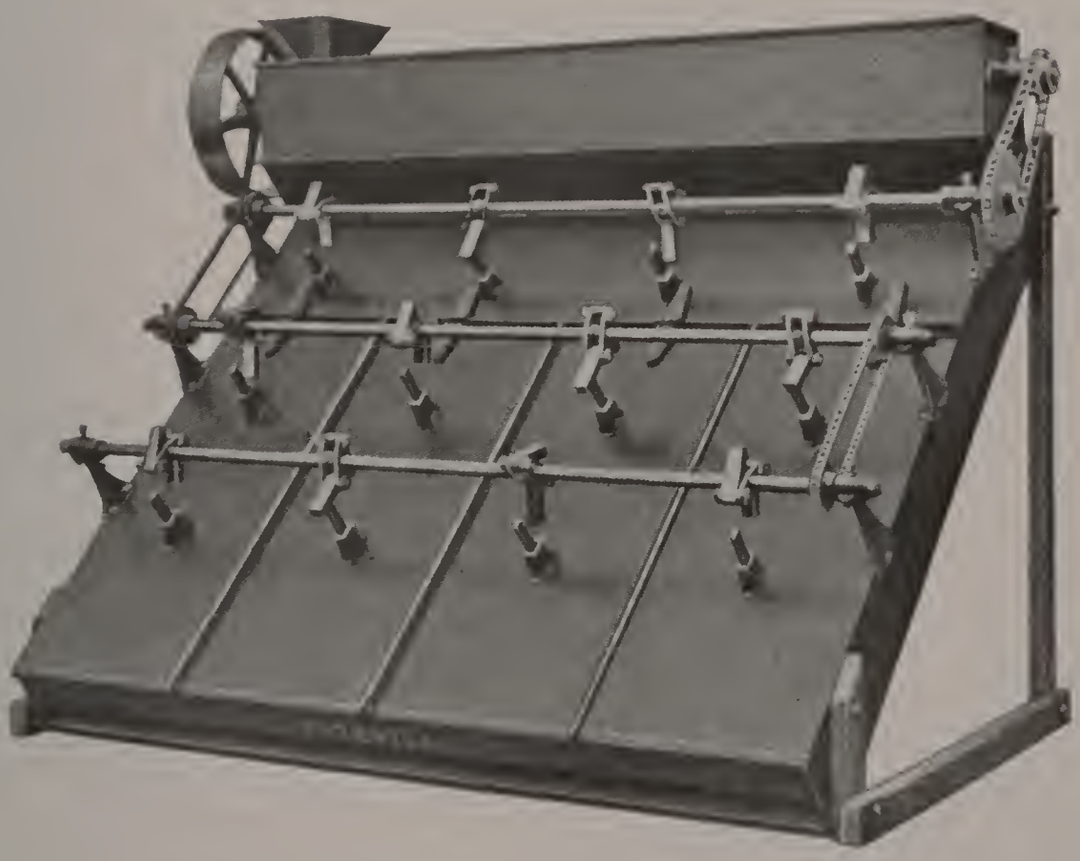
(b) The amount of concrete needed at any one time.

(c) The total amount of concrete used on the work, or during a given period of time.

The nature of the work will govern the type of plant to a great extent. If the work is closely confined to a small space or located in a fixed position, a stationary plant is to be recommended, with fixed storage bins and conveyors, so that the material may be carried to the plant by gravity or by special machinery, and the con-

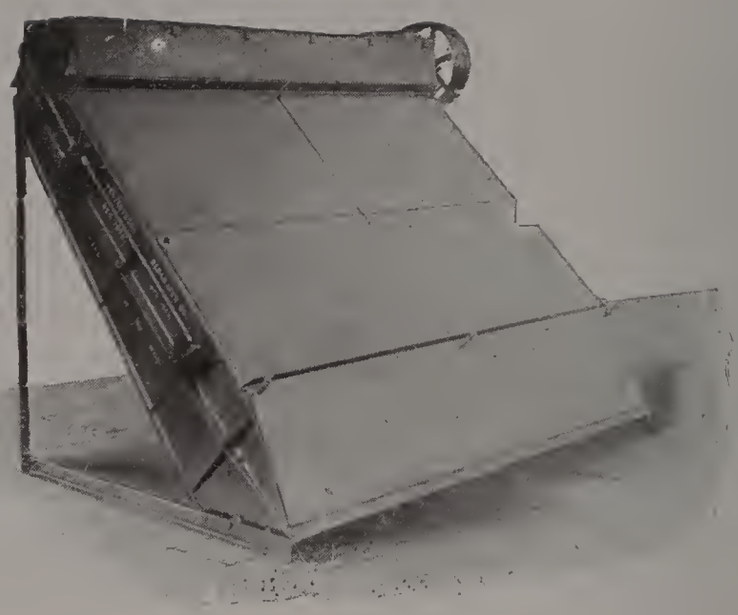


ROLL JAW CRUSHER.



SEPARATOR FOR GRADING SAND, GRAVEL, AND CRUSHED STONE.

The inclined screen is vibrated by successive tappings on the ends of the rods projecting up through the cover. Range of output, from ½-inch to 200 mesh. Capacity, from 500 to 40,000 lbs. per hour.

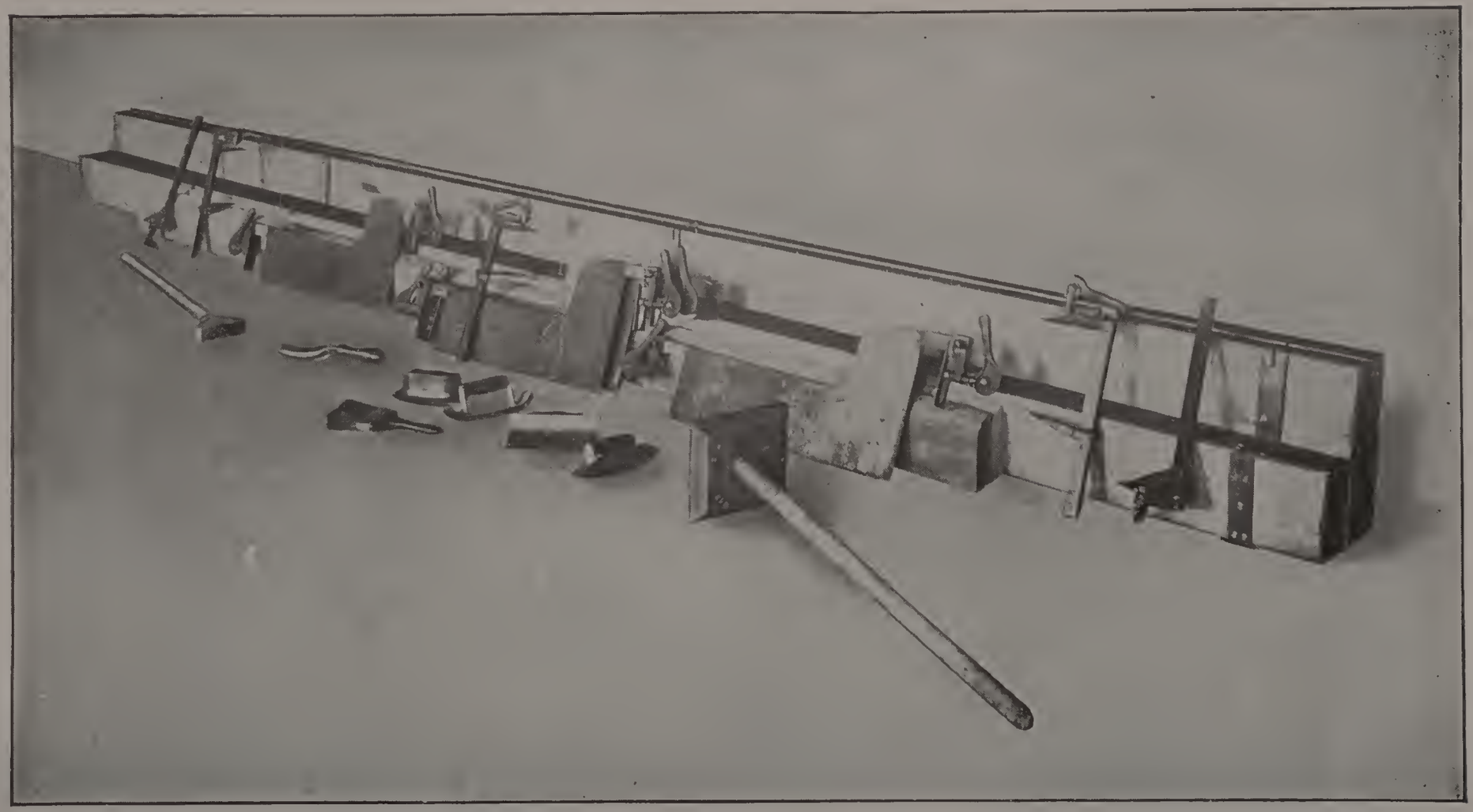


SEPARATOR.

For grading and separating sand, gravel, and crushed stone. Lower cut shows back open and bottom let down. For description, see page 259.

ADJUSTABLE LETTERING AND DATING STAMPS FOR STAMPING CONCRETE.

GANG OF WORKMEN LAYING CONCRETE IN STREET PAVING.



COMBINED CURBING AND GUTTER OUTFIT.

Designed for making three 5-foot sections at a time. Forms are of 2-in. pine lumber, bound with ¼-in. iron; sheet-steel dividing plates are provided with quick-locking clamps. The view shows tampers, edgers, jointers, and other necessary tools.

crete either used directly as it comes from the plant or removed by specially installed machinery or conveyors. Where the work is spread over a large area, or along a line of progress, as in road making, sewer construction, etc., the entire plant should be of such a nature that it can easily follow the line of work, thus making the concrete where it is needed instead of transporting it.

The amount of concrete needed at any one time controls the size of the plant and also the need for special handling equipment. Where only small amounts of concrete are to be handled, the investment of money in mixing and conveying machinery is not always warranted. In many cases where concrete is used in comparatively small amounts at irregular intervals, hand mixing and conveying is even more economical than machine work. One must realize that the loss of interest on the money tied up in machinery which is not performing work is like feeding a horse and letting him stand in the barn. To be profitable, equipment must be used, and must be able to produce more in the working days of its life than the same amount of capital invested in hand labor would produce.

The total amount of concrete required on a given piece of work, or on prospective and continuous work, will also govern the layout of the concrete plant. Where small amounts of concrete are to be used, the cost per cubic yard of

concrete made will be largely increased by adding the cost of such parts of the concrete plant as cannot readily be removed and transferred to the next job. For this reason, care should be taken to choose a plant which is compact, complete in itself, and easily moved. Even with the most economically arranged plant, and with an equipment which can be easily and speedily transferred from one job to another, the cost of dismantling the old plant, removing to a new location, and setting up ready for work again, is a factor to be considered, no matter how small it may be. Likewise, a certain percentage of depreciation is occurring for each day of use of plant, which must be considered, as well as the interest on money involved in plant cost.

The habit of disregarding such items as those referred to in the above paragraphs, has often led to a false estimate of the saving accomplished by the use of an extensive plant in locations and for purposes where a simpler plant would have produced better results.

The enterprise of modern manufacturers of machinery for the making and placing of concrete has responded to the increasing demand for better and quicker methods of construction. Likewise, the demand of the cement user who makes separately molded pieces has resulted in an extensive line of machinery for the manufacture of blocks, brick, shingles, roof tile, drain tile, fence-posts, sewer pipe, etc., which were formerly made in a crude way in rough molds.

These machines vary from the portable hand type up to the power-driven type which is capable of turning out large quantities of the finished product in a short time. For instance, block machines can be obtained in either the vertical-face ("side-face"), or horizontal face ("face down") type. Such machines may be fitted with mechanism capable of producing great pressure, or may be of a type in which the concrete is compacted by hand-power tampers. The variety of special face-plates and forms for special shapes of block, provides for a wide range of work.

The drain-tile and sewer-pipe manufacturer will find that his wants are met by machines ranging from the small hand-tamped and hand-operated single-piece machine up to the power-operated, automatically formed or pressed, revolving-platform type which requires a sufficient amount of concrete per day to make a mixer a practical necessity as part of the plant.

The sidewalk, curb, and gutter man will find that rigid but thoroughly adjustable steel forms are provided to take the place of his somewhat uncertain lumber members of early days, and also that special finishing and forming tools are available for all classes of work. These finishing tools may be obtained with either long or short handles.

In a similar manner, provision has been made to lighten, cheapen, and improve the work of the sewer and culvert builder through the use

of collapsible steel forms which may be quickly placed, quickly removed, and used for a great length of time.

As a suggestion to aid contractors and concrete workers who are seeking information in regard to modern methods of construction, and who are progressive enough to understand that a quicker and better way of doing things, where such methods may be really used to advantage, means more money for less effort on their part, we believe that time spent in close investigation at a Cement Show will prove to be a valuable asset to them. Catalogue descriptions of equipment serve their purpose well, as intended; but seeing the real thing and hearing its merits discussed, with an opportunity of asking questions yourself, is an entirely different proposition. The opportunity to compare machines and equipment with the object in view of choosing the tool, machine, or material best suited to your needs, is one which should not be neglected.

Since the equipment required in the various kinds of construction for which concrete is used at the present day varies nearly in proportion to the size of the work, no general hard-and-fast rule or recommendation can be given in choosing the required articles for a plant or for a given class of work. There are, as already intimated, certain fundamental considerations to be taken into account in each case. Materials have to be prepared and measured for the making of concrete. These materials must be con-

veyed to the place where the concrete is to be made, and, reaching the place of manufacture, are to be handled and changed into concrete. Then the concrete is to be conveyed to the place where it is to be used, and deposited in place with proper pressing or tamping in forms or containers of some sort, which will hold the soft mass in shape while the hardening process is taking place. If further finish is desired on the exposed face of the concrete, additional work will be necessary.

It will be seen that the above general principles apply just as well to the making of a concrete block or sidewalk slab as to the construction of an office building or breakwater. The difference lies in the way in which the materials are to be handled to produce the desired result—with possibly the same grade of concrete—in the easiest, quickest, and most economical manner.

Thus it may be easily understood that the equipment of the block-maker who mixes and handles but a small bulk of material at a time, would be far from satisfactory for the general contractor who uses his concrete by the dump-car load instead of by the shovelful. At the same time, up to the point of the actual placing of the mixed concrete, it is possible that the man who makes blocks or tile on an extensive scale may require as large and as nicely balanced an equipment as the bridge builder.

To give the reader an idea of the size to

which the machinery and equipment side of the concrete industry has grown in a comparatively short time, it may be well to call his attention to the following lists of equipment in which some of the different articles used in the concrete trade have been scheduled in a purely arbitrary manner.

Equipment Common to All Work. The first list contains equipment which may possibly be needed or used in all classes of concrete work, the use depending largely upon the size of the work. This list comprises crushing and grinding machinery for preparing rock in suitable sizes; screens and separators for grading sand and aggregate; washers for cleaning aggregates of loam or other impurities that would weaken the concrete or retard the setting; shovels, hoes, spading forks, rakes, and spades; wheelbarrows, hand-carts, and cars; elevators and conveyors for handling both the raw material and the concrete itself; concrete mixers, either power-driven or operated by hand; tampers of both plain and special design; miscellaneous machinery, such as boilers and steam engines; gas, gasoline, and oil engines; electric motors, etc.

Additional Equipment for Special Construction Work. The second list might be confined to the use of the general contractor who constructs buildings, bridges, etc. In addition to the first general list, this man may need an excavating outfit and buckets; wheel scrapers;

hoists, and derricks; wall ties and forms; adjustable steel forms for building hollow walls; steel forms for silo, well, or cistern work; clamps for holding molds; bar benders and bar twisters; shears for cutting reinforcement; grout mixer and ejecter; steel chutes and special buckets for placing concrete; dump-cars for use on large work; heater for materials in cold weather; stucco machines for placing stucco finish; floor surfacers for finishing granolithic or terrazzo floors; trowels and floats of various kinds; patent spades for wall finish; pneumatic finishing tools; brushes for scrubbing finished surfaces; hammers and chisels for facing walls; flare lights for night work; etc.

If this same man also handles road work, sidewalks, curbs, gutters, sewers, and culverts, he may need a road roller; adjustable steel curb, gutter, and sidewalk forms; steel sewer and culvert forms; an outfit of special hand tools for sidewalk and curb work; special tampers for sidewalk surfaces, etc.

Equipment for Separately Molded Work. Another list might be added for the manufacture of separately molded articles of concrete, such as blocks, drain-pipe, etc.—this outfit to comprise, in addition to the first list, concrete-block machines, with special molds for various finishes and designs of block; chimney molds; porch column molds; fence-post molds; ornamental molds for balusters, caps, etc.; cement brick machines; both hand and power sewer-pipe and

drain-tile machines; cars, carts, special wheelbarrows, and racks for handling blocks, tile, and other shapes; automatic block tampers, etc.

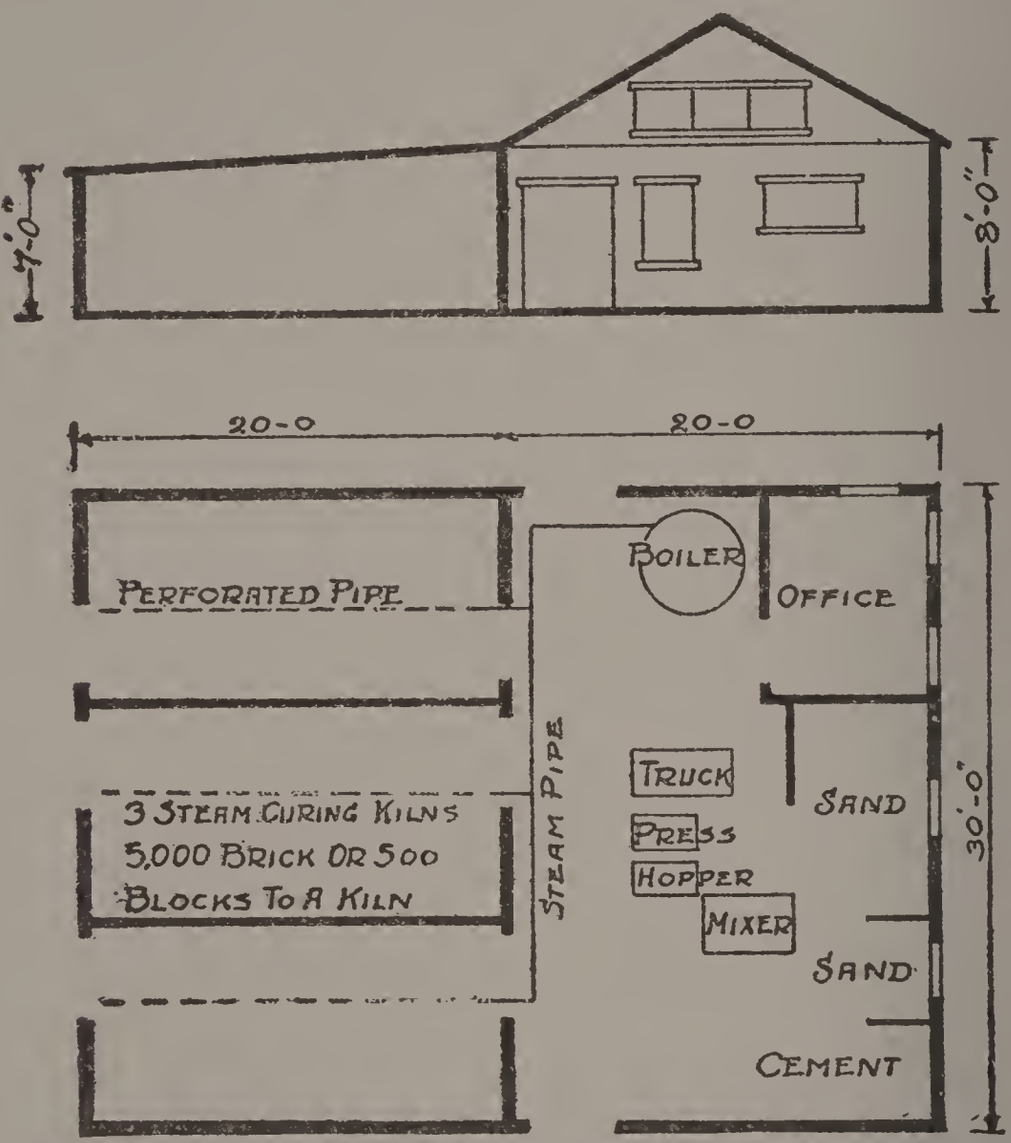


Fig. 35. Typical Layout of Small Block or Brick Manufacturing Plant.

Fig. 35 shows a typical layout for a small brick or block plant.

The reader must not understand that all of the above equipment is necessary in order to do successful work in concrete construction, as this is not the case. Many pieces of work will not warrant the purchase of special equipment of any kind; and, in fact, a sufficiently good job

often may be done with the ordinary tools and stray pieces of lumber to be found around the suburbanite's cellar or the farmer's woodshed. The majority of such equipment as named above is intended for the contractor and cement worker who makes the article purchased a part of his stock in trade, and contemplates using the tools, machines, steel forms, etc., many times each month or year in following his trade. In this way the cost of the equipment is divided up over a large amount of work, and proves a good investment to the owner through his ability to earn more money or to do better work in a given time by its use than he would have done by the use of some crude or makeshift apparratus.

Since space is not here available to attempt a full description of the modern equipment contained even in the partial lists given above, we are forced to confine our attention only to an outline of the equipment used in the operations connected with the manufacture and placing of concrete under ordinary conditions. Literature in regard to all kinds of tools, machines, and accessories is always to be had by applying directly to the manufacturers of the articles in question.

HAND TOOLS

The hand-operated tools and devices used in ordinary concrete work comprise shovels, spades, hoes, rakes, screens, pails or buckets, hose, sand and gravel measuring boxes, wheel-

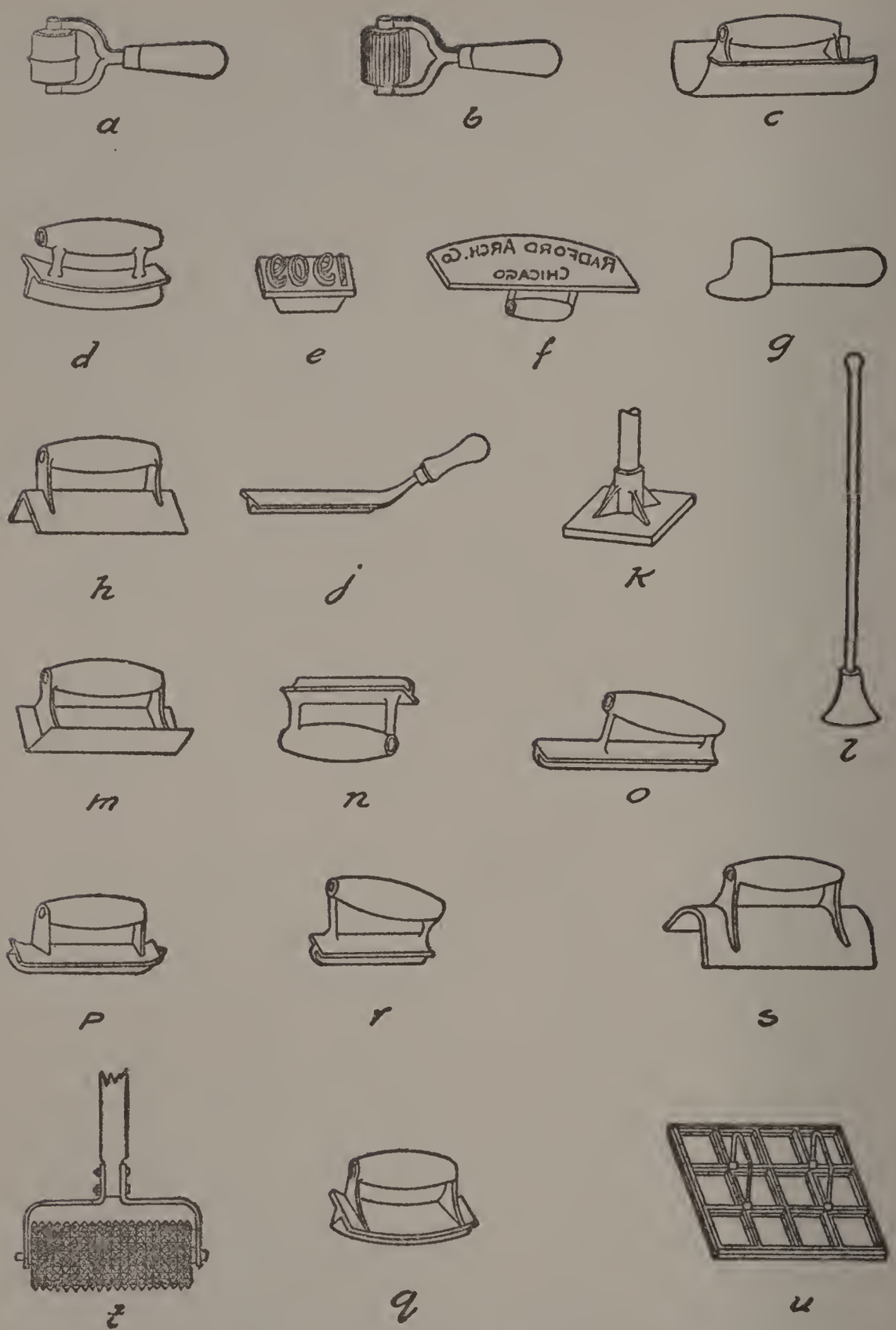


Fig. 36. Concreting Hand-Tools.

a—Rotary Jointer; b—Fluted Roller; c—Round Corner Smoothing Trowel; d—Sidewalk Edger; e—Date Stamp; f—Name Plate; g—Radius Tool; h—Square Corner Smoothing Trowel; j—Brass Jointer; k—Tamp; l—Tamper; m—Square Corner Smoothing Trowel; n—Jointer; o—Jointer; p—Center Knife; q—Driveway Groover; r—Hand Brass Jointer; s—Round Corner Smoothing Trowel; t—Indenting Roller; u—Driveway Impression Frame.

barrows, tampers, concrete board and runways, besides a number of special tools of steel, iron, brass, or bronze, for marking and finishing joints, surfaces, and edges, squaring and rounding corners, etc. Many of these special tools are illustrated in Fig. 36. There may also be purchased **long-handled tools** which enable finishers to do their work from an upright position instead of getting down on their hands and knees.

TAMPERS

In addition to **hand tampers,** mentioned above, there are **pneumatic tampers,** operated by compressed air. These are used for ramming the mixture in block and other molding machines, as well as in forms where concrete is placed in mass, and in concrete pavement and curb and gutter laying. The air is supplied by hose connection with an air-compressor, and always in control of the man operating the tamper. The tamper heads are changeable and of various shapes to accommodate themselves to various widths of space, corners, etc.

There are also **automatic power tampers,** usually driven by a small gasoline engine or by electric motor. The tamping is done by a gang of tamper hammers, which consist of detachable wooden blocks or metal heads connected to eccentrics mounted on a revolving shaft, and so set around the shaft that as some of the tampers are coming down, others are going up. The force of the blows is regulated by a lever which

is pulled down a greater or less distance, lowering or raising the tampers; and the driving pulley is automatically disengaged when the tamping is done and while the block or bricks are being removed from the plate. The power tamper is especially adapted to rapid work and large output.

CRUSHERS AND GRINDERS

In the processes of grinding and crushing, the expenses incurred through consumption of power, necessity for repairs, and delays resulting in loss of output, are ordinarily excessive. In the case of a grinder, the direct loss due to excessive wear of parts often results in a yearly cost for repairs amounting to from one-third to one-half the original cost of the machine. The efficiency of a good grinder, therefore, will depend on its economy of power consumption, its compactness and strength of construction, and its capacity of output.

In grinders of the **revolving ring and rolls** type, the underlying principle is that of a free, vertical, concave ring, yieldingly supported on three rolls pressing against its inner face and having a free movement relative to one another. The lateral freedom of the ring allows it to adapt its position relatively to the material being ground, so that the line of least resistance to crushing of the material is automatically found, and the crushing is accomplished with a minimum of wear and power. As the ring re-

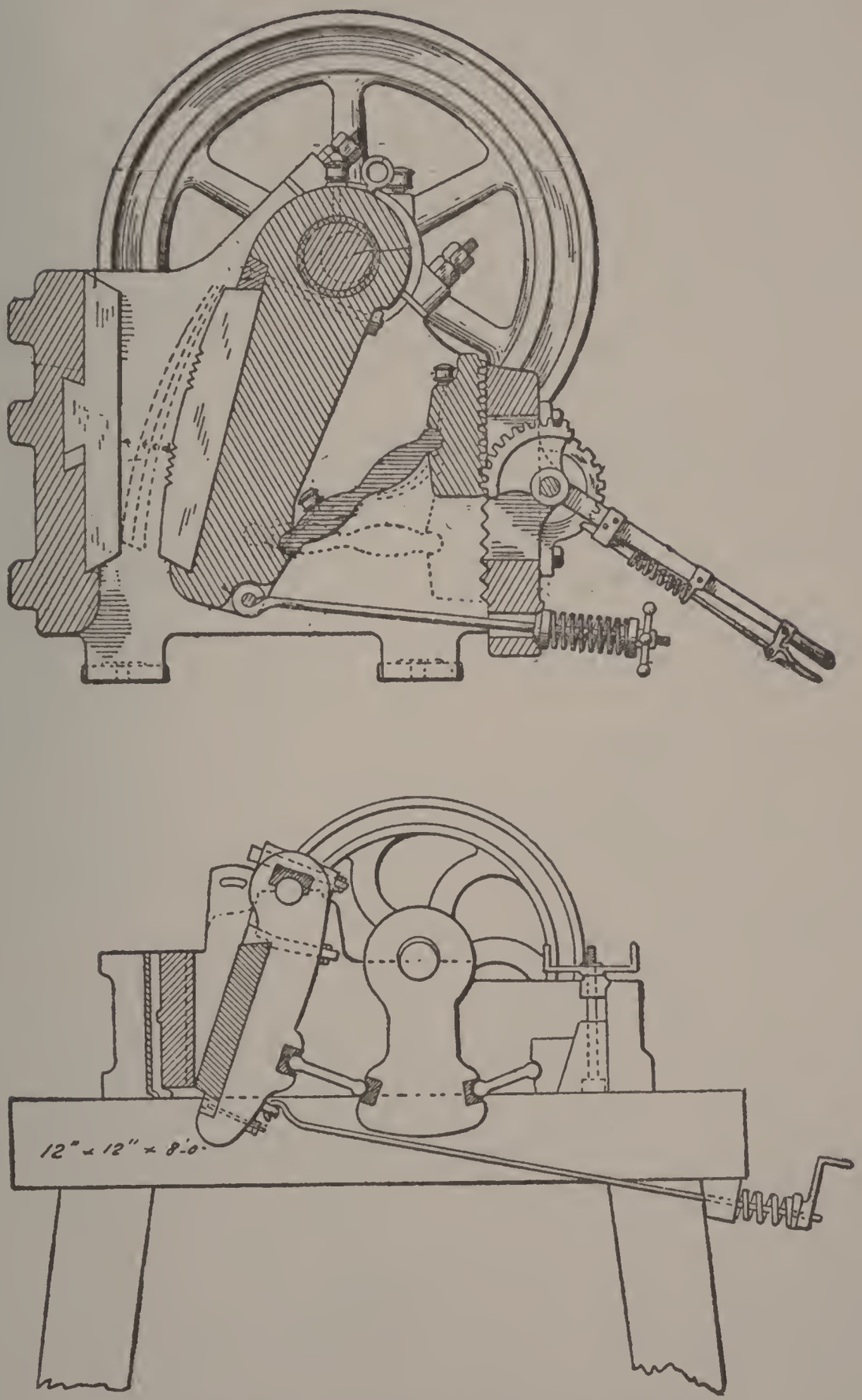


Fig. 37. Crushers of Roll-Jaw Type.

volves, the three rolls press against its inner face. These are the four wearing parts. The rolls are convex, and the ring is concave, and tracks on the rolls. The springs support the rolls yieldingly, and the rolls support the ring, so that the four crushing parts are free to move to pass iron or uncrushable objects, and are cushioned to take up shock and vibration and prevent crystallization or breakage. The feed falls onto the inner face of the ring. Centrifugal force holds it there in a layer an inch deep. It revolves with the ring, and passes under the rolls. The rolls are pressed by the springs outwardly against the material on the ring, with a crushing pressure adjustable by the screws to as high as 20,000 pounds. The rolls roll over the material, crushing it against the ring. The crushed material flows off each side of the ring into the casing, and falls to the discharge.

The body of material between the rolls and the ring makes most of the material abrade on itself in crushing, thus reducing the wear on the wearing parts.

Crushers of the **roll jaw** type are illustrated in Figs. 37 and 38. A special safety link-plate is provided for such cases of emergency as when unbreakable material is dropped between the jaws of the machine. Adjustments are very readily effected for greater or less fineness of crushing, by means of the screw and hand-wheel, the angle of the link-plate being changed, thus adjusting the peculiar motion of the crushing

jaw, which, being semi-rotary and at the same time reciprocating, facilitates the crushing of the hardest rock. Any degree of fineness, it is claimed, may be obtained—from 4-inch size in rock or clinker, hard or soft, to sand, at one

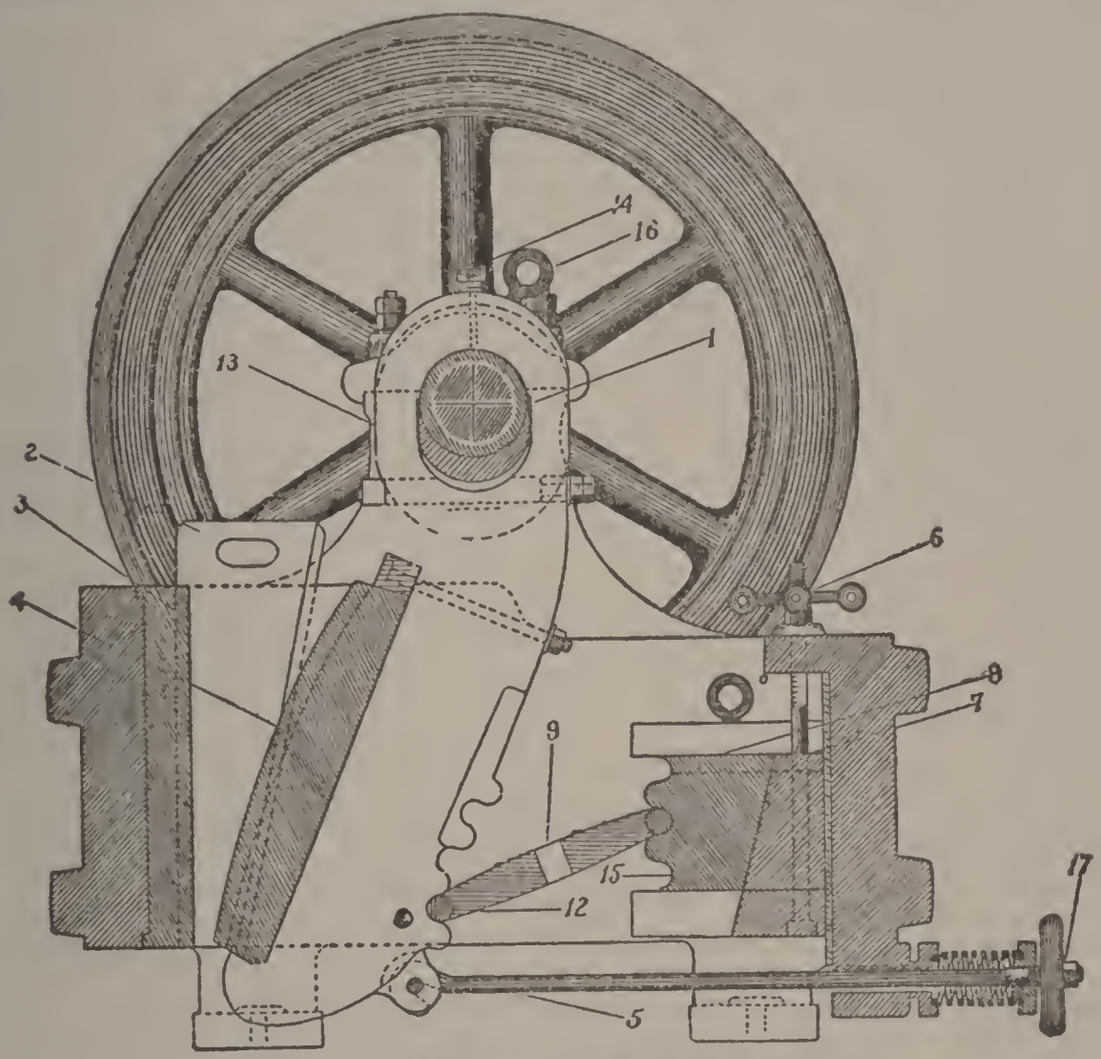


Fig. 38. Crusher of Roll-Jaw Type.

operation, from the raw sizes to the fineness required in the processes of cement manufacture.

Roll-jaw crushers, in the small sizes, are frequently of the pitman or heavy connecting-rod type; in the larger sizes, of the cam-and-roll type, the latter keeping the best adjustment under heavy wear and operating with the least vibration.

Crushers are also of the **gyratory** type, the material being fed into a hopper with interior revolving and stationary mechanism.

Very frequently—especially where the quantity of material to be crushed is large—**crushed stone elevators** are operated in connection with the crushing plant, to deliver the product directly to the stock pile or to dump-cars. They are adjustable to various heights by raising or lowering the long conveyor frame. They consist in principle of a series of buckets carried on an endless chain or belt-conveyor revolving on rollers, usually chain-driven, carried on a long, rigid frame.

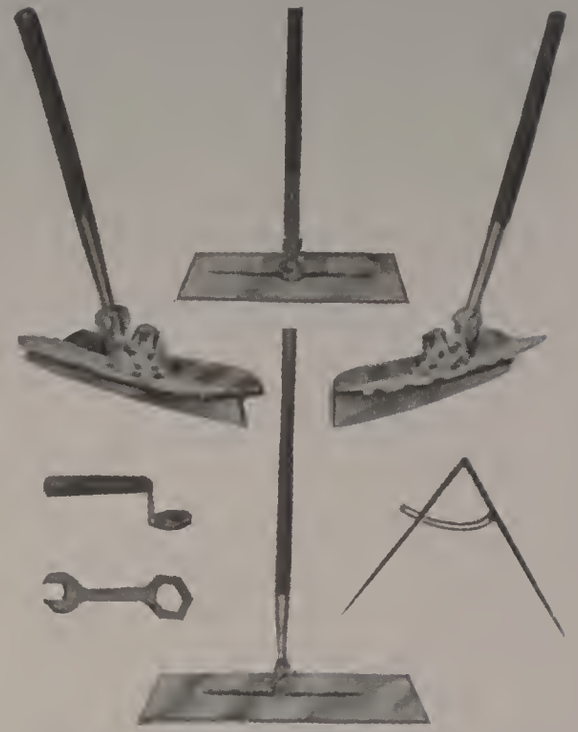
SCREENS AND SEPARATORS

Under this head we find a considerable number of devices employed for separating and grading the coarser and finer particles in natural sand and gravel and in crusher-run material.

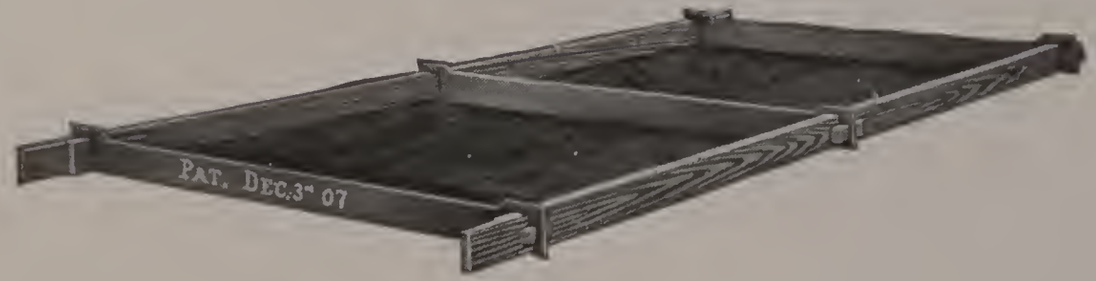
The simplest form of screen, commonly used in small operations, consists merely of a large, oblong sieve which is placed on end at an incline, and against which the material to be screened is thrown in successive shovelfuls by the workmen. The finer ingredients, passing through the meshes, drop to the ground or platform, and accumulate in a heap behind or underneath the screen.

In larger operations, and particularly in those cases—as in some of the processes of Portland cement manufacturing—where the utmost accu-

AUTOMATIC TAMPER.

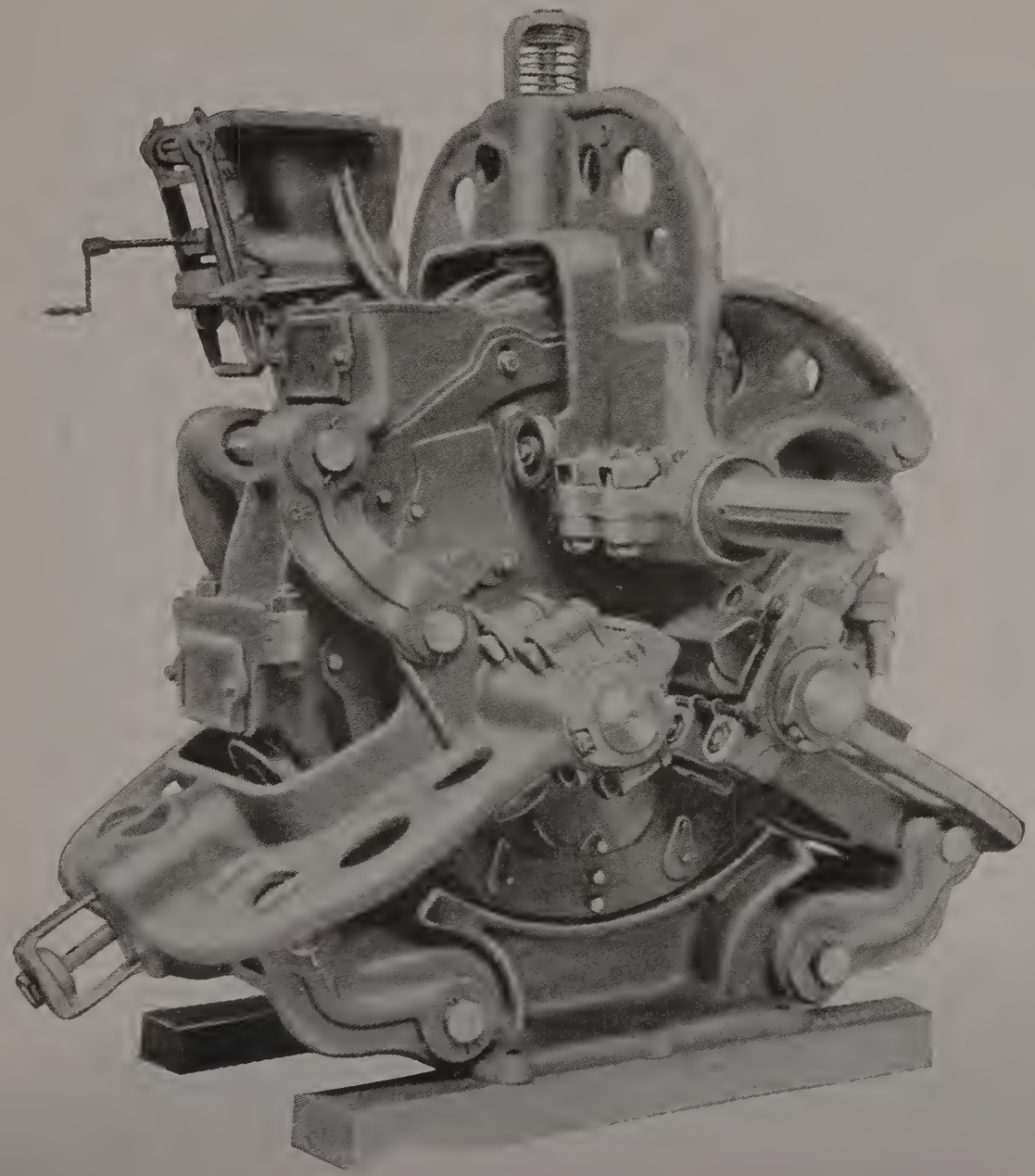


LONG-HANDLED TOOLS FOR CONCRETE WORK.

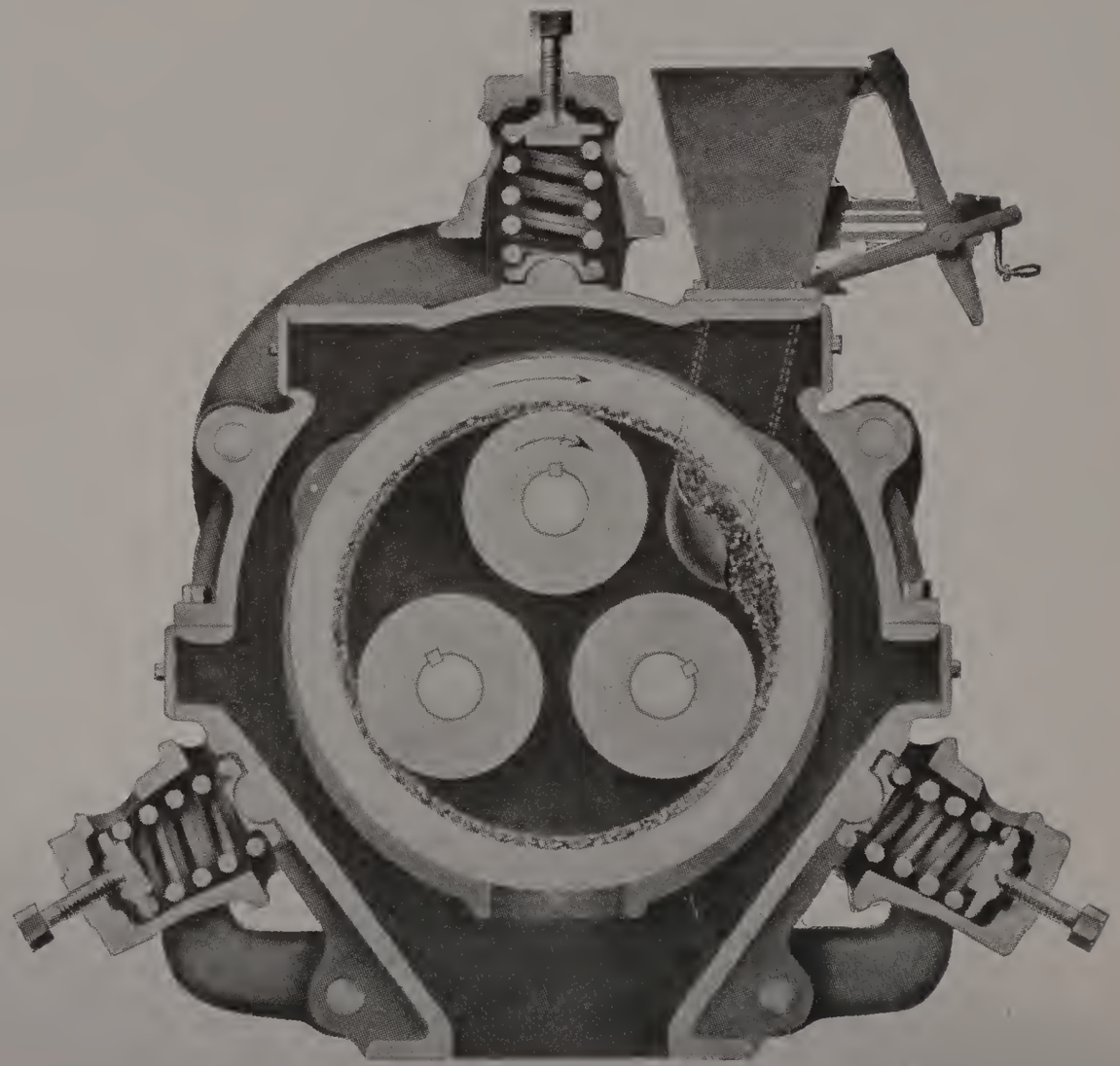


FORM FOR CONCRETE SIDEWALK.

Showing use of ties and dividing plates for making expansion joints and holding side-rails without use of stakes or braces.

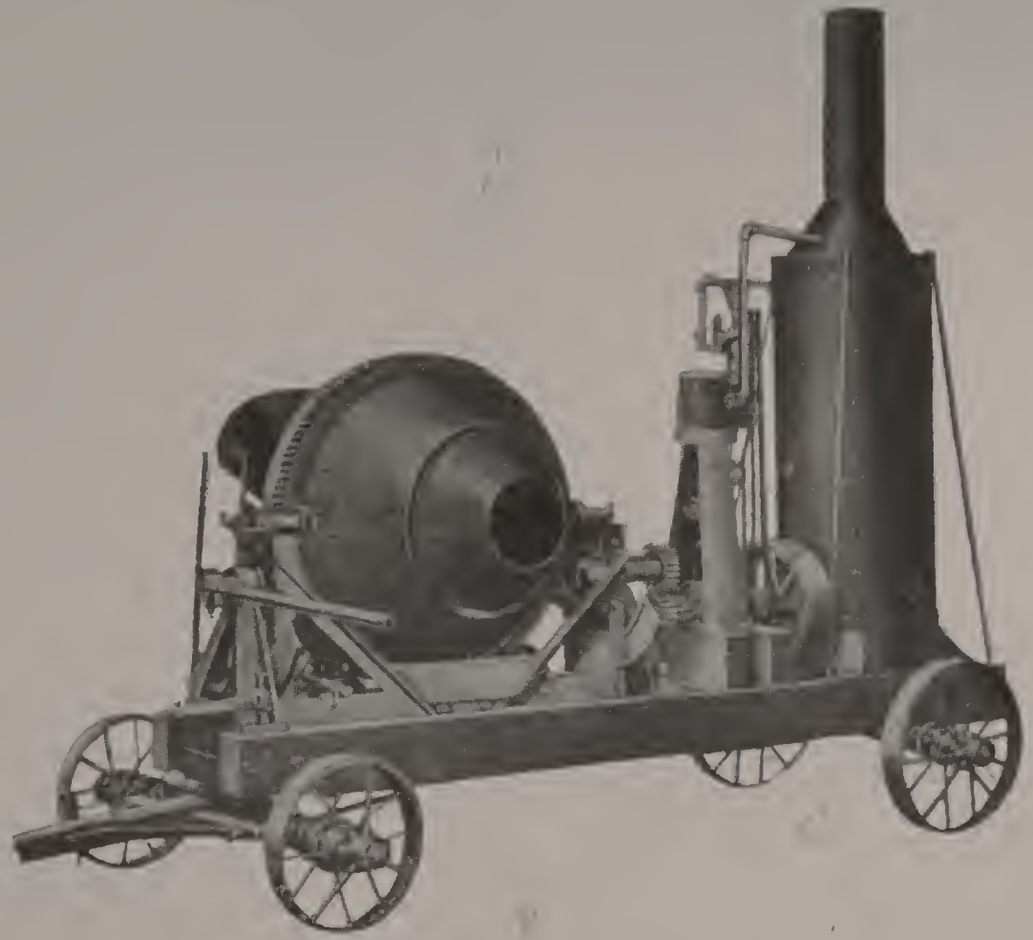


Exterior View.



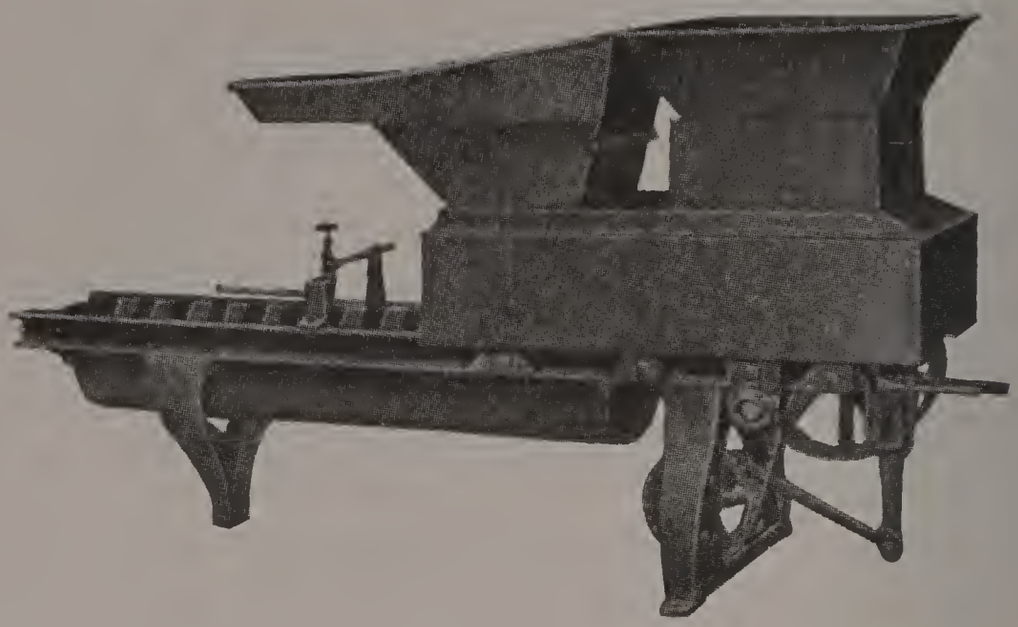
Sectional View Showing Interior Mechanism and Method of Operation.

GRINDER OF REVOLVING RING AND ROLL TYPE.

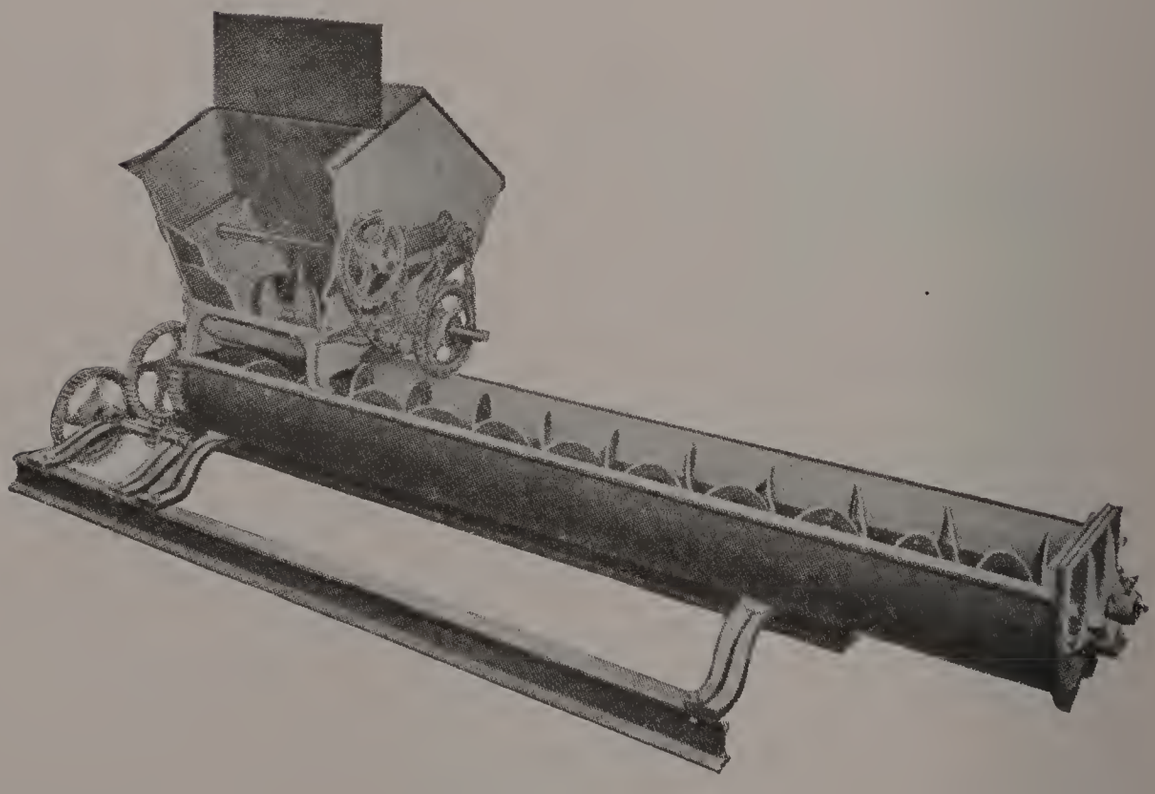


CONCRETE MIXER OF BATCH TYPE MOUNTED ON TRUCK, WITH STEAM POWER.

INTERIOR OF DRUM.

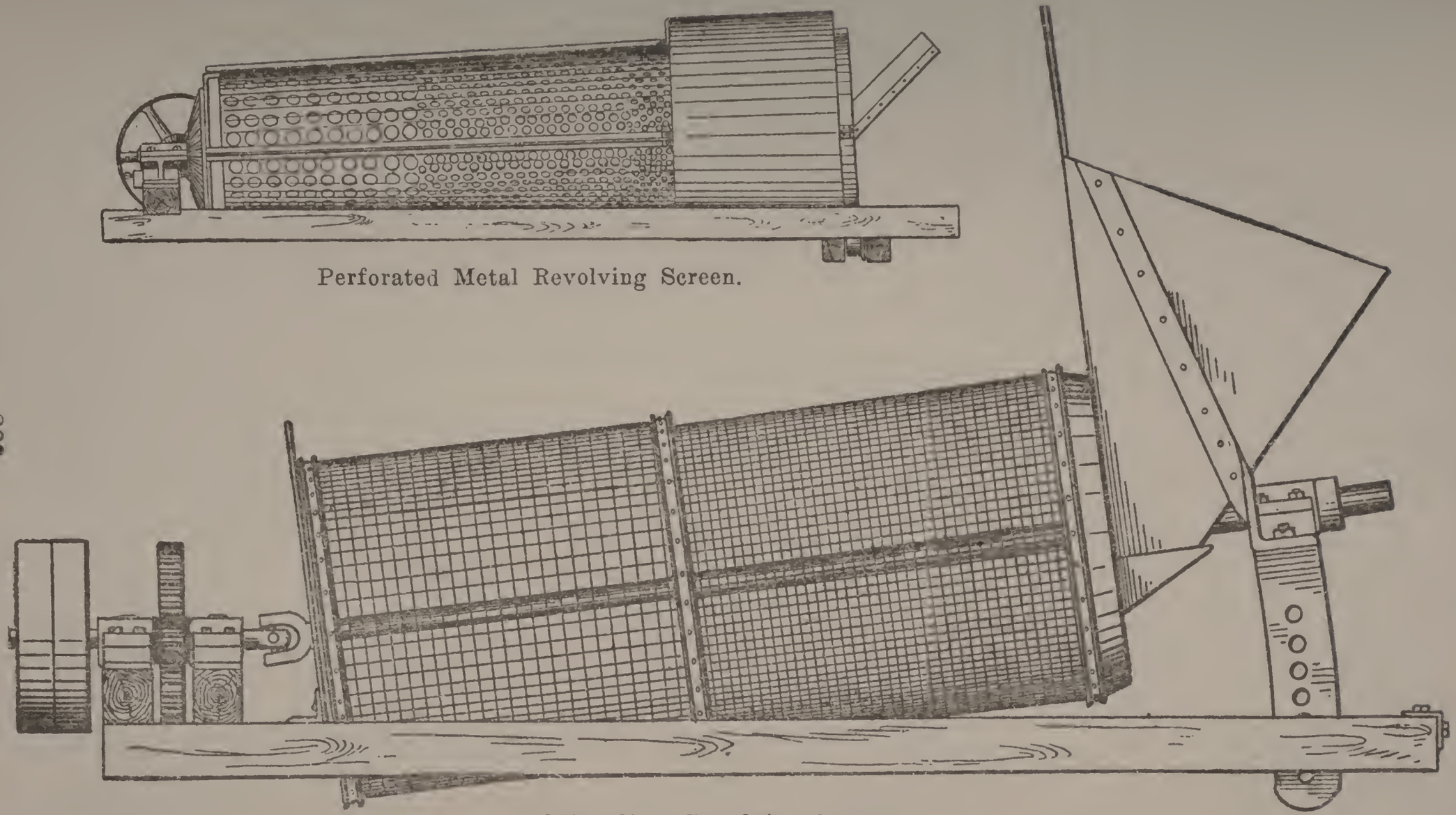


CONCRETE MIXER OF PUGMILL TYPE.



CONTINUOUS MIXER.

Perforated Metal Revolving Screen.



Wire Cloth Revolving Screen.

Fig. 39. Typical Examples of Revolving Screens for Separating Sand or Screenings from Gravel or Crushed Stone.

racy in the grading of materials is necessary, hand screening is wholly inadequate, and recourse is had to mechanically operated screening devices.

Very efficient machines of this class are found in the various types of **revolving screens** now on the market. Examples are illustrated in Fig. 39. These screens consist essentially of cylinders of perforated metal or wire cloth mounted at a slight incline and slowly revolving on a gear-driven shaft. The finer meshes are at the upper end, the coarser at the lower end. The material to be screened is fed from a hopper or chute into the revolving screen at its upper end, and the successive sizes of ingredients are automatically separated by passing through the meshes as the material slowly finds its way to the lower end of the screen.

Several important types of machines known as **separators** have been developed, consisting essentially of an inclined, mechanically vibrated screen, entirely enclosed so as to be dust-proof.

With machines of this class, the fineness of output is controlled to a considerable extent by adjusting the supporting legs of the machine so as to change the inclination of the screening surface, which has the same effect as diminishing or increasing the screen mesh. The screen can be withdrawn for replacement or cleaning through a door at the upper end of the separator box, or through the hinged front cover.

The feed conveyor distributes with regular-

ity over the screen surface. The steel screen frame maintains a uniform tension of the screen cloth, promoting the vibratory impulses. The simple device for producing vibrations secures movements rapid and sharp, but of small amplitude. In some separators the design admits using either one or two screens, and any mesh cloth up to a fineness of one hundred.

The purpose of the machine is to separate all moderately dry, pulverized materials. The vibrations are sharp and cleansing, and give material in process the least possible projection, offering it innumerable opportunities to pass through the clean screen openings before the tailings escape at the foot. The material is fed into the hopper, from which it is distributed in a continuous, thin stream over the entire cross-surface of the screen. The cloth is automatically kept in tension, and vibrated by the constant tapping of small knockers. As the material flows down the screen, the finer matter passes through the meshes, and the tailings escape over its foot.

Details of Contracting Equipment

For ordinary small or medium-sized jobs, where the concrete is to be manufactured by hand, the necessary equipment has already been described. (See page 156.)

Another type of construction plant which may be used to advantage where a considerable amount of concrete is to be placed, may consist

of an equipment similar to that above referred to, with the exception that a small machine mixer, either hand or power, may take the place of the mixing board used in the other outfit. Machine mixers are of different types, and may be arranged so as to be easily moved from one part of the construction to another, or may be located at one part of a stationary plant—as,

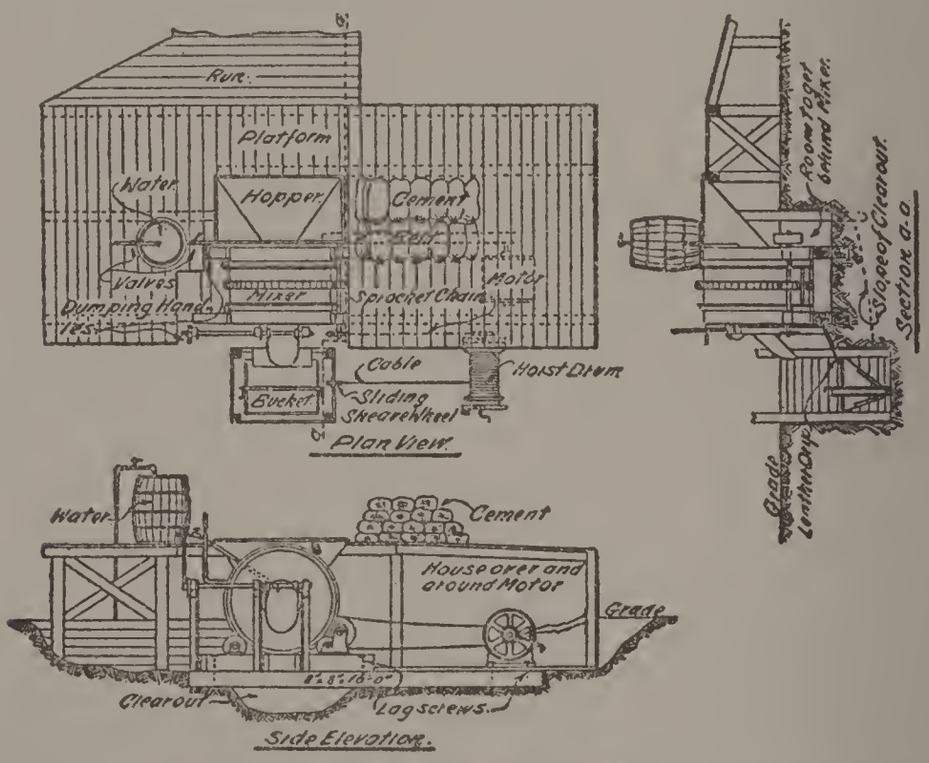


Fig. 40. Well-Arranged Layout for a Machine Mixing Plant.

for instance, in the block or tile industry—and surrounded by other equipment and machines. In such a case, the storage bins for cement, sand, and gravel or broken stone are located near the mixer, or these materials are conveyed by gravity to the mixer from fixed bins. Also, the concrete from the mixer is conveyed by a belt, elevator, or chute to storage hoppers which feed the special machines of the plant.

In the ordinary construction plant where the concrete mixer is really the center which controls the arrangement of the other parts of the plant, the equipment may consist of carts or cars for conveying the raw materials to the stock piles; shovels and spade forks for handling materials; wheelbarrows or hand-carts for bring-

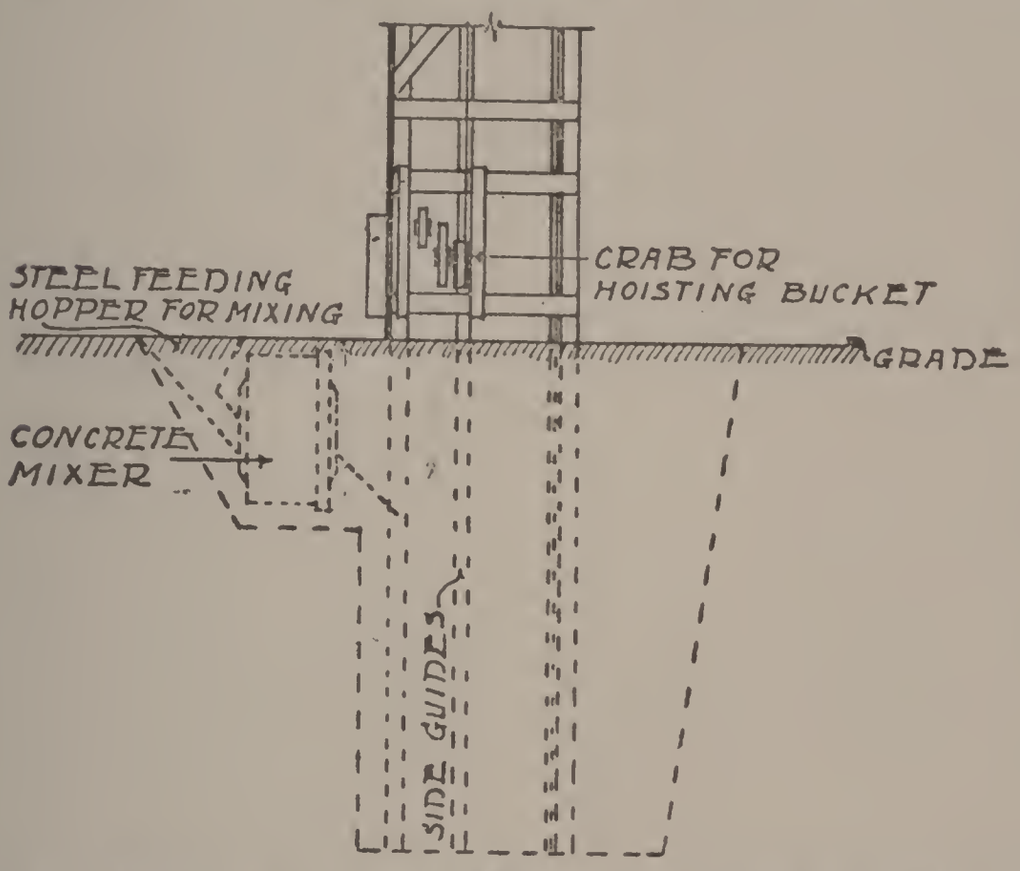


Fig. 41. Mixer in Pit, with Materials Supplied at Grade, and Concrete Removed by Hoist.

ing materials to the mixer and carrying away the concrete; runways; water barrels, buckets, or hose; mixer with motive power; derricks and buckets for conveying materials or concrete; elevators; belt-conveyors or steel chutes for delivering materials or mixed concrete; tampers; spades for finishing, etc. If the work is near a base of supplies, a rock crusher may be

needed for crushing the aggregate, and screens for grading crushed rock or sand. A machine-mixing plant in operation is shown in Fig. 40.

The location of the mixer may control the equipment for transportation to a considerable extent. Figs. 41 and 42 show this point to good advantage. Wherever the force of gravity may

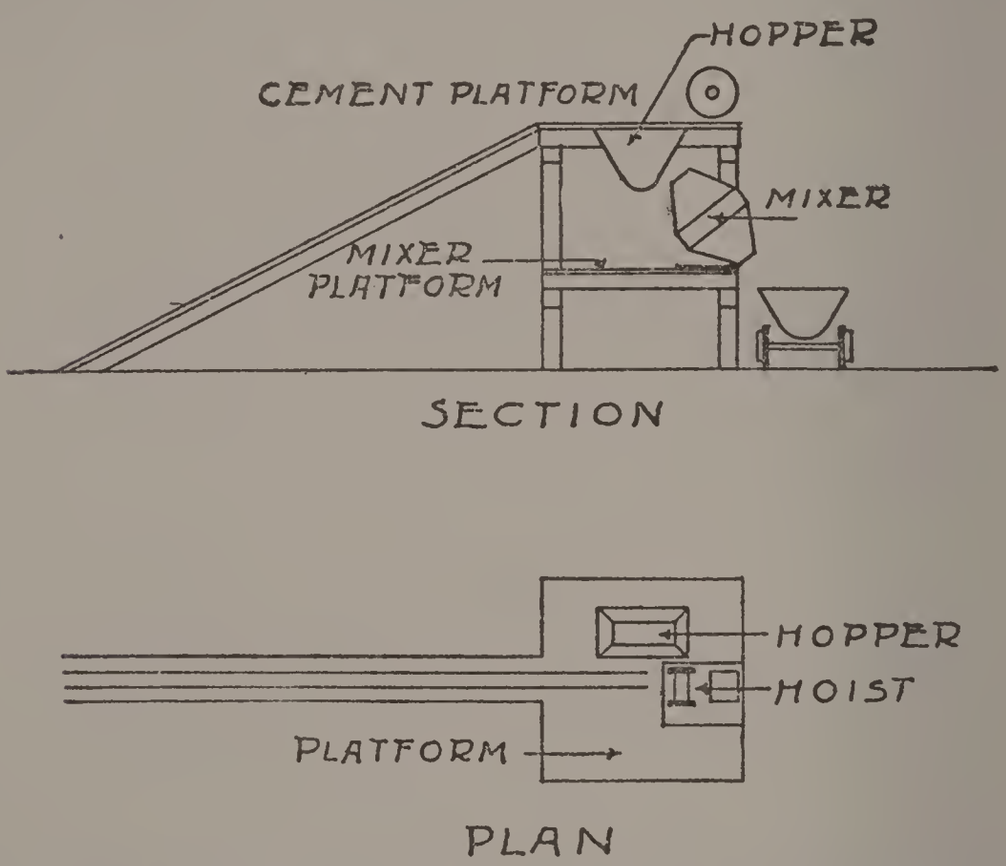


Fig. 42. Mixer on Platform, with Materials Supplied by Small Cars, and Concrete Removed at Grade.

easily be made use of in delivering or removing materials to or from a mixing plant, a certain amount of work is saved. Likewise, where concrete can be delivered directly from the mixer to a conveyor of some type which will carry the concrete to a location near the place where it is to be used, manual labor is reduced to a great extent.

Since the concrete mixer forms such an important part of the general make-up of a concreting plant, it may be well to describe the general types of machines in common use.

CONCRETE MIXERS

Concrete mixers comprise two general classes —**continuous** mixers and **batch** mixers. With the "continuous" type, the feeding of the materials, the mixing, and the discharge of the concrete form one continuous process which may be carried on indefinitely. With "batch" mixers, on the other hand, only certain measured quantities of cement, sand, etc., are fed to the machine, and only a definite quantity or "batch" of concrete is made and discharged at a single operation, the process being repeated as often as may be necessary. Some mixers are designed so that they can be adjusted to do work either continuously or in batches, and thus combine features of both classes of machines.

In continuous mixers, the general mechanical principle is that of a long screw or pug-mill, the mixing being done in a long drum by means of blades or paddles mounted on revolving shafts, which, somewhat like the thread of a screw or the blades of a propeller, agitate the materials and at the same time shove them along toward the discharge end of the drum. In the combined type, the discharge opening in the drum may be closed, the feed cut off, and only a batch mixed at a time.

Concrete mixers are further distinguished according to their mechanical construction and operation, into three classes—namely, **gravity** mixers, **revolving** or **rotary** mixers, and **paddle mixers.**

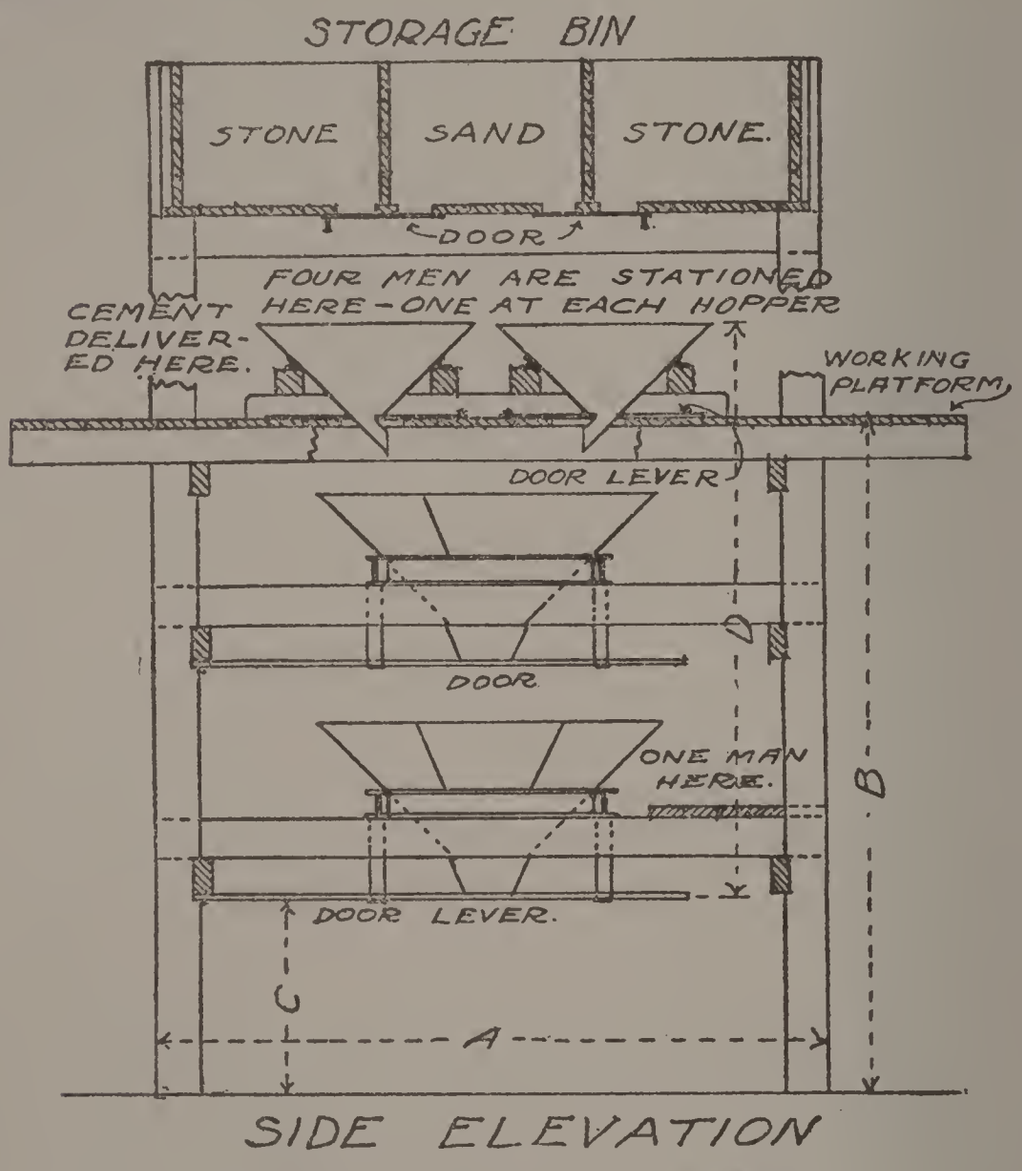


Fig. 43. A Type of Gravity Mixer.

In the gravity type (shown in Fig. 43), as the name indicates, the operating force is that of gravity. The materials are mixed by simply being thrown down through an inclined chute or through a succession of hoppers. On the interior surface of the chute type of gravity mixer are

fastened projecting members in the shape of pins or blades, which are successively struck by the materials in their descent. These mixers are usually constructed of sheet steel, and may be had in sectional form adjustable to the greater or less height of the raised platform from which the materials are dumped.

In the hopper type of gravity mixer, the shape of the hopper causes a kind of "turning inside out" motion in the mixture as it slides from one hopper into the next. Portable hopper gravity mixers are often used with a derrick. Then the first hopper is filled at the stock pile, water added, and the concrete mixed while being swung from the stock piles to the place where it is to be used.

Mixers of the gravity type were the earliest mechanical mixers used.

Rotary mixers comprise a great variety of commercial types. In general, they consist of a hollow, revolving drum or box usually power-driven, but sometimes operated by hand. In some cases the shape of the box or the form of the plates composing the drum, combined with the manner of mounting, is depended upon to do the mixing as the machine revolves, without the assistance of any interior paddles or blades. In other cases, blades or deflectors are mounted in the interior of the drum, in positions calculated to intercept the material, cut through it, and throw it about from side to side, thus mixing it thoroughly.

Many machines of this rotary type can be filled and discharged while running. In the **tilting** type of batch mixer, the drum is suspended in a frame in such a manner that one end of the drum may be raised and thus allow the concrete mixture to flow out by gravity. The **non-tilting** type of batch mixer has steel deflectors of one type or another on the inside surface of the drum, which plow through and pick up the batch as the drum revolves. When it is desired to discharge the batch, a swinging steel chute is projected into the discharge opening of the drum, and the batch is discharged by falling from the deflectors into the chute.

The batch type of mixer is suitable for either a fairly constant delivery of large amounts of concrete on big jobs, or for small quantities at irregular intervals. Concrete of exact proportions can be produced with certainty and regularity, and at all times the regulation of the mixture is in the hands of the person in charge. The amount of mixing of the dry materials before the addition of water, as well as of the wetted mixture, is controlled by the person running the mixer; and any desired number of turns of drum may be specified. Since the water enters the mixer with a given charge of concrete, the exact amount of water per batch can easily be regulated.

In the continuous type of mixer, either the properly proportioned cement, sand, and broken stone are shoveled directly into the mixing

drum, or these materials are fed automatically from hoppers located over the mixing mechanism. In the automatic type of machine, the feeding device may be set for any proportions desired, and the machine will maintain these proportions if properly designed.

The more special features of the continuous type of mixer may be summed up in its ability to produce large quantities of concrete without interruption, and with a degree of accuracy of mix which depends largely upon the method of feeding or the design of the feeding mechanism. The materials are fed into the mixer simultaneously from the feeding hoppers; and, in the automatic type, dry mixing takes place until the mixture has proceeded well along the length of the mixing drum. In most machines the feeding hoppers are provided with some form of device to prevent clogging or arching of the dry materials and a corresponding irregularity of mixture. Some types of continuous mixers can be run as batch mixers by shutting off the feed and closing the end of the discharge drum. A complicated and very effective mixing action is attained with a properly designed screw or mixing blade or paddle.

In the case of batch mixers, the charge may be proportioned away from the mixer, then wheeled, shoveled, or dumped directly into the charging end of the machine; or it may be placed in an elevating charging bucket on the ground, raised, and dumped into the mixer. Some mixers

are built low enough to load from a wheelbarrow directly or by the use of a low incline, while others need some type of elevating or overhead loading device. In any type of large mixer, a charging apparatus of some sort will reduce the number of men needed.

The method of proportioning and feeding the raw materials to the mixer, and the method of introducing the necessary water for the mixture, vary in different types of machines. Some are fed by automatic measuring devices for both materials and water, while in others the materials are measured independently from the outside.

Equipment for furnishing the raw material to the mixer need consist only of shovels, wheelbarrows, and small carts if the supply piles are located in a favorable position. If the mixer has a charging device, all loading and wheeling of materials may be done at ground level; otherwise elevated charging platforms or hoppers may be needed, with runways leading from the ground.

The transportation of concrete from the mixer may be accomplished by means of wheelbarrows or small cars or carts, or by buckets and conveyors. Often the concrete is dumped from the mixer directly into wheelbarrows, which are placed on an ordinary platform elevator and carried up to the elevation at which the concrete is to be used. This plan is a substitute for the more elaborate equipment shown in Fig. 44. Various

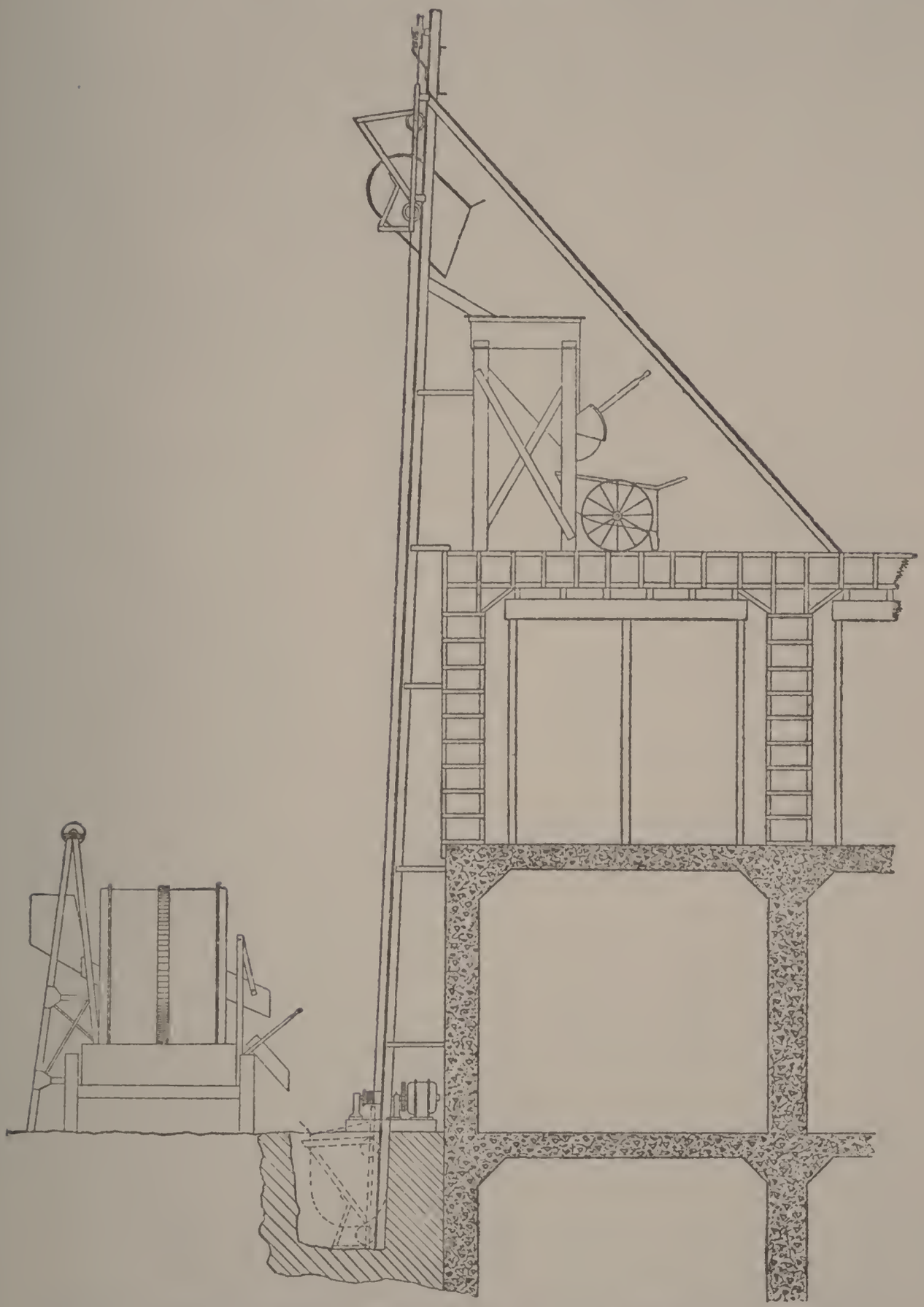


Fig. 44. Concrete Mixer Used with Hoist for Elevating Concrete.

An outside installation—including power mixer, electrically operated hoist, and automatic tilting bucket distributing by gravity.

forms of similar hoisting apparatus with automatic dumping devices are to be had upon the market. As shown in Fig. 44, the concrete is stored in a bin at the desired level, and drawn off into barrows or carts for use at a point near-by.

A plan which produces good results in the case of a batch mixer, is to have a hopper built over a stationary mixer, as shown in Fig. 42, so that a complete charge may be placed in this reserve hopper while the batch in the machine is being mixed. The use of a reserve hopper really gives an additional mix to the mass, due to the operation of loading the hopper and then discharging into the mixer. The cement is added to the material while filling the reserve hopper.

One of the earliest types of rotary mixers developed consisted essentially of a cubical box revolving on a shaft passing through diagonally opposite corners, and fed and discharged through a door in one side. No dependence was placed on interior disintegrator blades or scoops, the mixing being entirely the result of the motions imparted to the contents by the sides and ends of the box as it revolved.

This same fundamental principle is embodied in some mixers of the present day, the old-time shaft being replaced with hollow trunnions riding on rollers and large enough to serve as openings for charging and discharging the mixer. The box-like drum is rotated by gearing which meshes with the teeth on a circumferential rack

fastened around the box or drum at right angles to and midway between the trunnions. An auto-

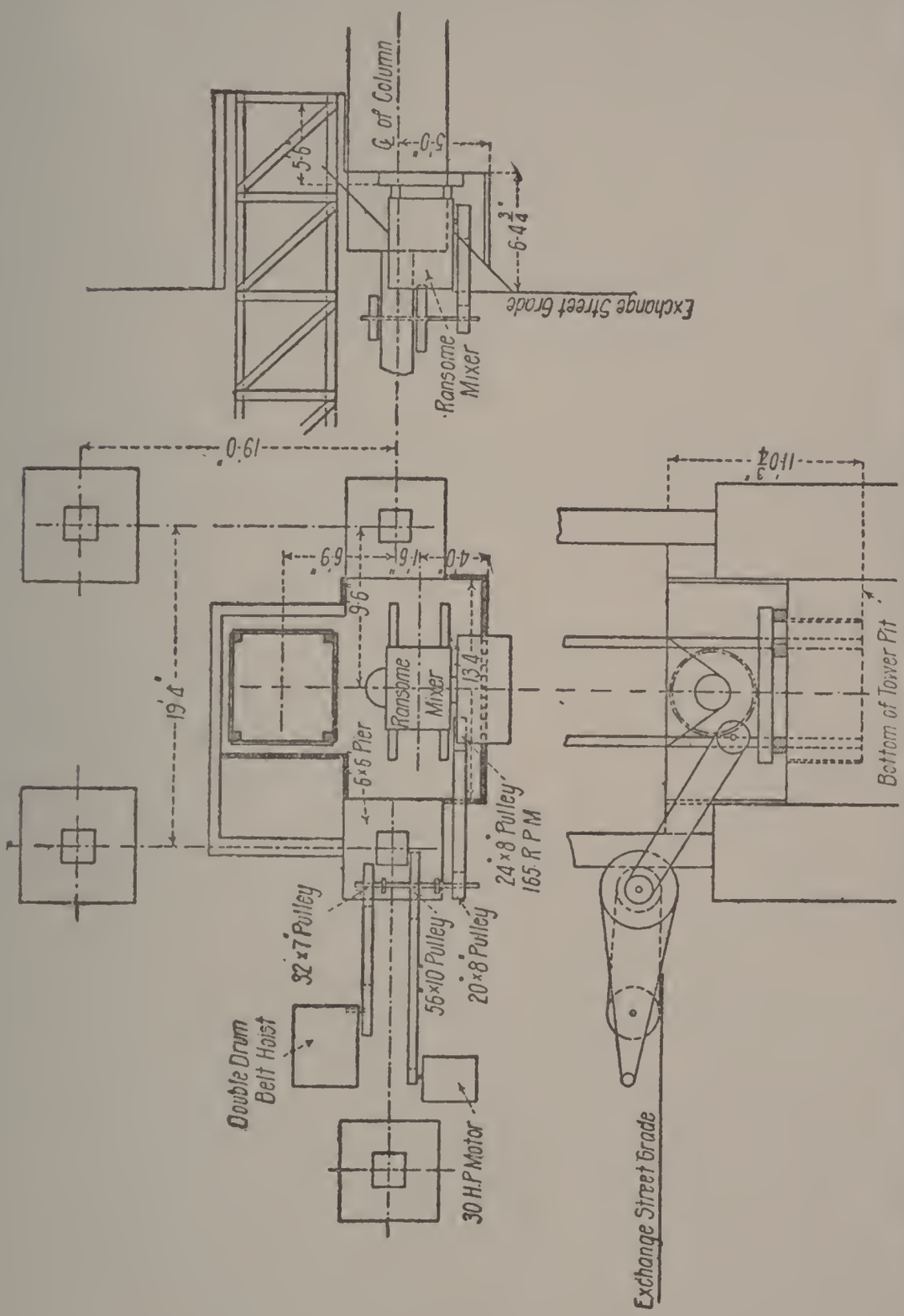


Fig. 45. Layout of Concreting Plant Used in Construction of Large Reinforced Concrete Warehouse in Buffalo, N. Y.

matic power-dumping device, which can be operated by the man running the engine, is used in tilting the drum for discharge; and, instead of

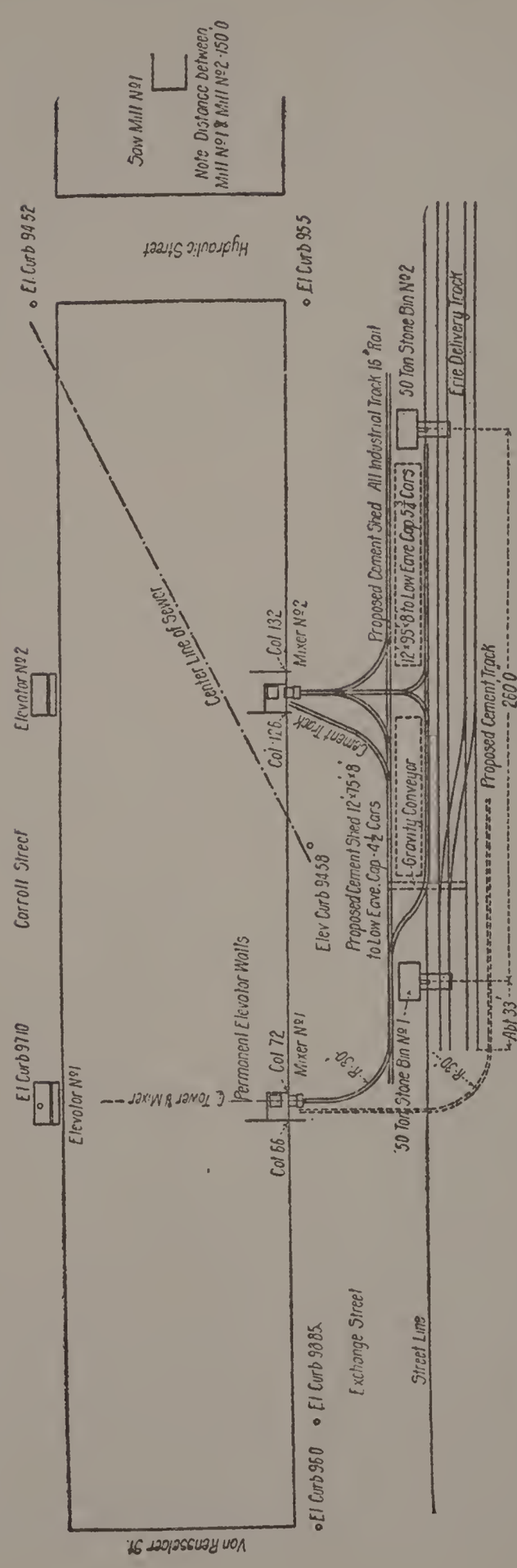
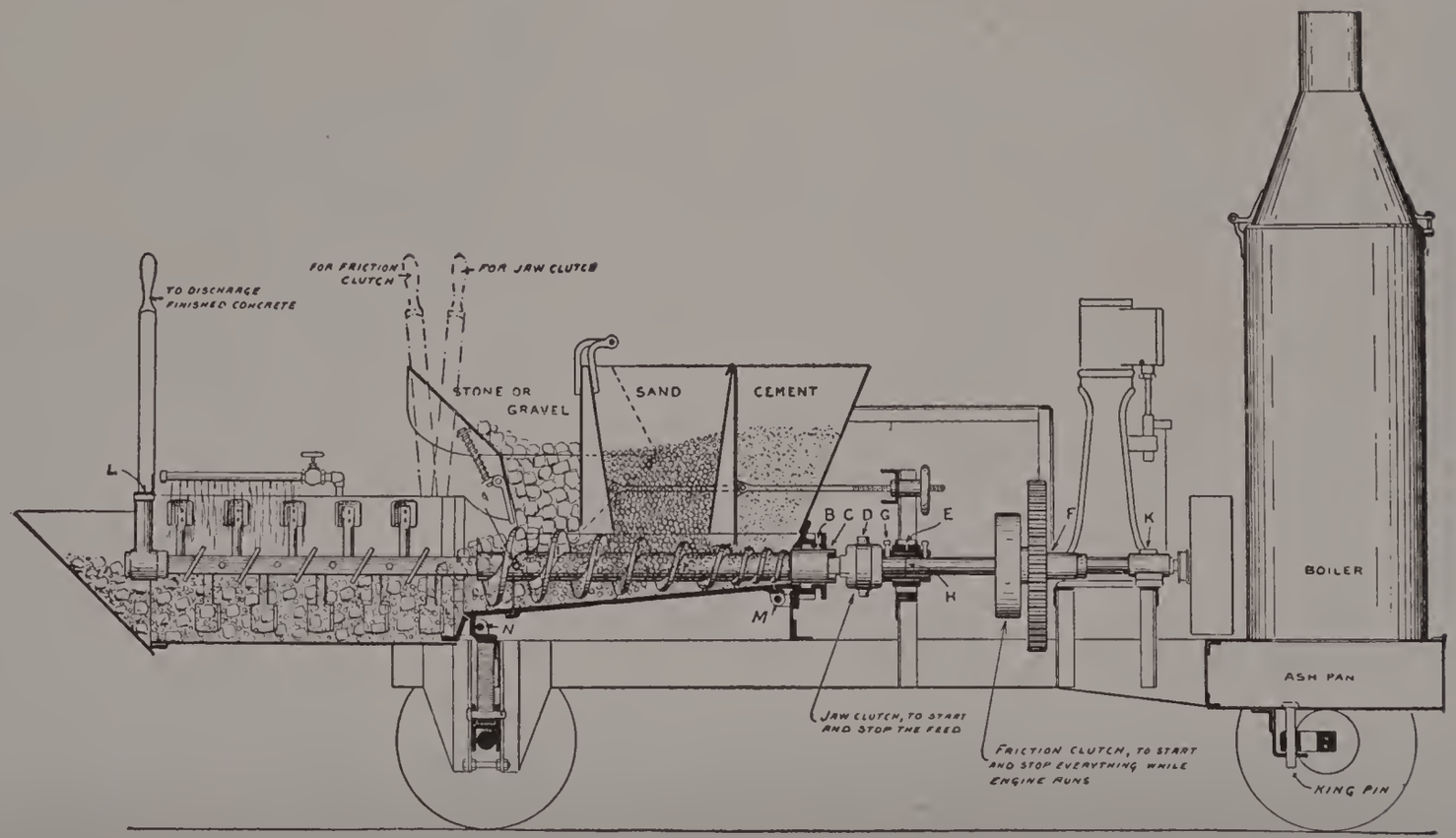


Fig. 46. Layout of Concreting Plant for Construction of a Large Reinforced Concrete Warehouse in Buffalo, N. Y., Showing Method of Handling Material.

CONSTRUCTION OF LUDLOW AVENUE VIADUCT,
CINCINNATI, OHIO.
Concrete carried 550 feet; piers being put in during high water.

SPOUTING PLANT USED BY WESTLAKE CONSTRUCTION CO., IN BUILDING THE CINCINNATI HOSPITAL.

BOOM-SUPPORTED SPOUTING PLANT WITH RADIUS OF WORK OF ONE HUNDRED FEET.



AUTOMATICALLY PROPORTIONING CONCRETE MIXER.

Combined batch and continuous type. The proportioning, which can be altered while mixer is in operation, is effected by a conical screw and two gates regulated by hand-wheel, the position of the gates determining the amounts fed by the screw. Mixing paddles are mounted on same shaft with screw. Ingredients first mixed dry, then wet.

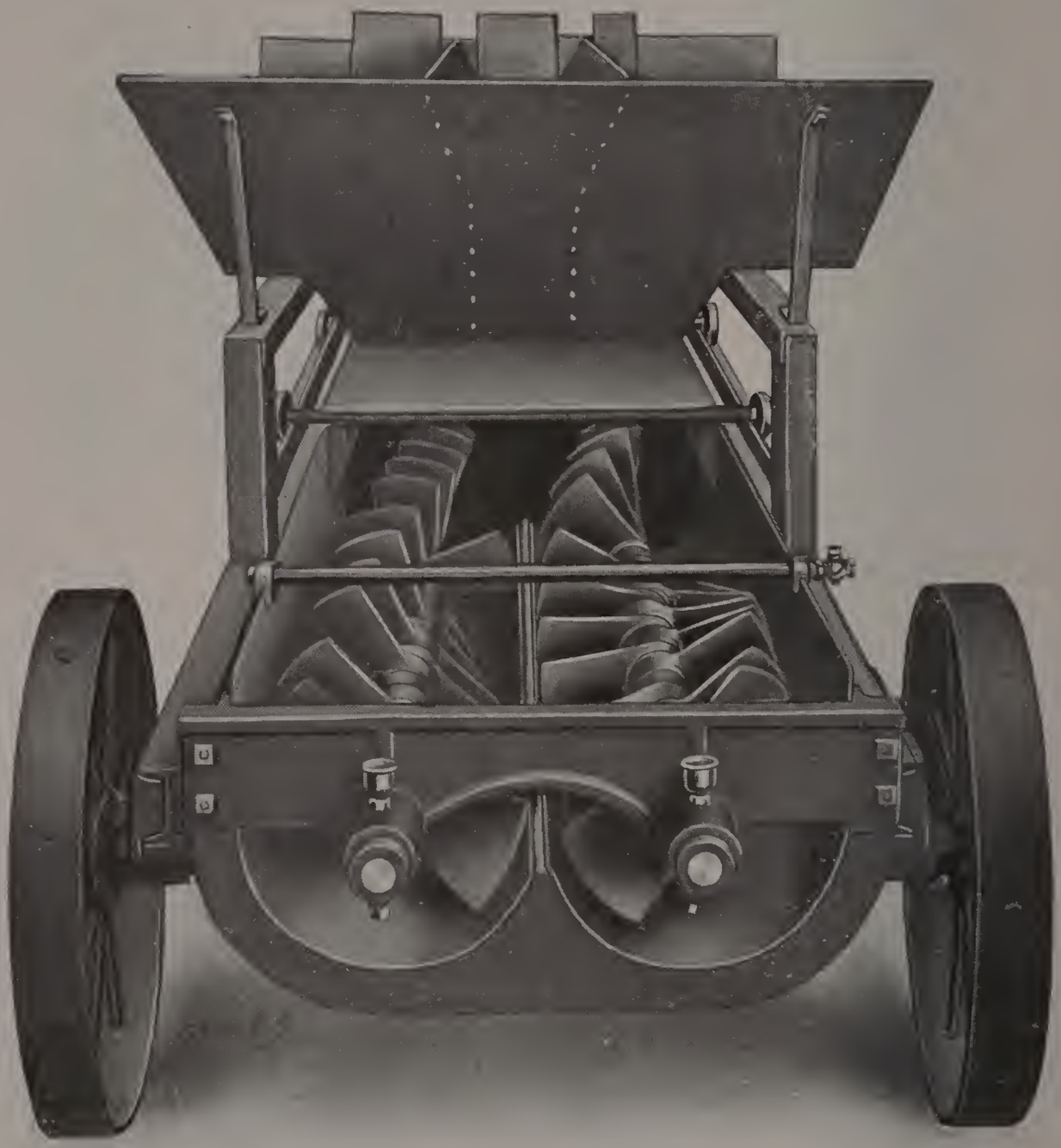
SPECIAL TYPE OF MIXER FOR STREET WORK AND OTHER WORK WHERE CONCRETE IS DISTRIBUTED QUICKLY OVER LARGE AREAS.

Bucket travels on an I-beam track, but can be stopped and discharged at any point.

BATCH MIXER OF NON-TILTING TYPE

BATCH MIXER OF TILTING TYPE.

Mounted on short skids, and here shown in dumping position.



DOUBLE-TROUGH CONTINUOUS MIXER.

the sharp corners of the old-style box, the corners are rounded, which gives a box of larger capacity in the same space and eliminates the opportunity for pocketing of the fine mortar.

Another example of a rotary mixer characterized by entire absence of interior wings, blades, or deflectors to assist in the mixing process, is illustrated in Fig. 47. Here dependence is placed solely on the peculiar shape of the

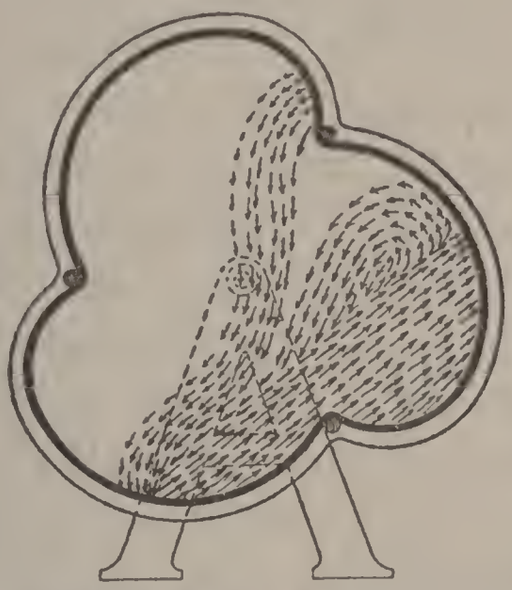


Fig. 47. Involute Curved Drum Concrete Mixer.

drum and the series of movements it imparts to its contents, both of which are indicated in the diagram. In section, as shown, the drum consists of a series of **involute curves.** These afford no angles or corners for the pocketing of material. As each curve is carried in turn to the bottom, it is instantly filled and covered by the falling charge. Continuing in its revolution upward, it rises out of the mass, cutting out and bringing up the bottom of the mass with it, and depositing it over the top with a scattering mo-

tion as it falls. The ends of the drum are made cone-shaped, also having involute curves, and these serve to cause a travel of the materials from the ends toward the center, where the corresponding curves in the straight part of the drum are constantly carrying up, cutting through, and turning over the entire charge. Discharge is effected by tilting the drum.

Street Paving Mixers. Under this head come a number of commercial types of machines designed especially for laying concrete for street paving, but adaptable to a wide range of work in which concrete has to be deposited rapidly over large areas, as, for example, in the construction of bridge abutments, retaining walls, etc. These machines are usually equipped with an elevating charging bucket holding the full capacity of the drum, and an automatic water-measuring tank to furnish the right amount of water for each batch. The distributing bucket, self-dumping either by tilting or by bottom-dumping, travels on a beam track which may be 18 to 25 feet or so in length, and which swings horizontally through an angle of about 170 degrees, thus enabling an area up to 50 feet or so in width to be covered. The bucket can be stopped and discharged at any point.

Hand-Power Mixers. In work where perfect uniformity of concrete is essential, and especially where large quantities of concrete are to be handled, machine mixing should always be employed. This does not mean that a large and

expensive equipment is necessary where only small or medium quantities of concrete are to be handled; nor is power a point which determines whether a machine mixer should be used. There are several small machines on the market which may be turned by hand if desired, and which, if handled correctly, will produce as good a grade of concrete as the larger machines with special arrangement for power.

Amount of Mixing

While all agree that no concrete should be used which is streaky or not thoroughly mixed, some engineers say that no matter what may be the printed directions of the makers, no batch of concrete should be discharged from a mixer until it has had twenty turns. In the case of continuous mixers, these engineers tell us that the length of the trough or drum should be such that the materials will be turned a number of times equivalent to twenty turns per batch; or the drum should be closed at the end, and the machine run as a batch mixer until the concrete has been properly turned.

A test often used in determining whether a mixture of materials is uniform throughout after a given number of turns, is to put a small quantity of red oxide of iron into the mass to be mixed, and then observe the distribution of color in the mass for a stated number of turns of the machine.

When work is stopped, the mixer should be

washed out, and care taken that no concrete be allowed to remain in any part of the interior.

The consistency, or degree of wetness, of mixed concrete varies from a dry mixture up to a very wet or mushy mixture. A dry mixture is often considered as of about the consistency of damp earth. Water will rise to the surface of a dry mixture only as a film which appears after prolonged tamping. Dry concrete is used for heavy foundations in dry locations, and where heavy loads are to be withstood a short time after placing. Concrete of this consistency must be placed in the forms in layers not over 6 inches thick, and then rammed thoroughly.

A medium or quaking mixture is of a jelly-like consistency, and will shake on ramming. Such mixtures are adapted for use in ordinary mass work, such as foundations, heavy walls, and piers.

A very wet or mushy concrete is one which will run off a shovel unless handled quickly, and will not support the weight of an ordinary tamper. This grade of concrete is suitable for use in thin walls, columns, floors, tanks, or in reinforced concrete work. Its nature allows it to flow readily around the steel and to fill all parts of the forms easily. Wet concrete will give a denser mixture and provide a smoother surface on the finished member.

For construction of ordinary size, the mixer outfits as put out to-day by leading manufacturers are very complete. Apparatus for charg-

ing, running, and for supplying the water in definite quantities, forms a part of the machine itself. About all that remains is to provide materials of a proper nature, proportion them in a definite manner, use intelligence in running the machine, and remove the concrete as fast as it is ready.

These points being attended to, if the subsequent precautions described above as necessary during the setting and hardening are observed, satisfactory results will be assured.

Special plant layouts for work of ordinary size are shown in Figs. 40, 41, 42, and 44; and for larger work, in Figs. 45 and 46. It must not be understood that any one of these layouts will surely serve best on any particular job, unless the most careful examination of local requirements dictates it. In fact, as already stated, each job is a problem in itself.

What we have endeavored to show is that, even on small or unimportant work, there is a proper and an improper way to mix concrete. Also that the manufacturers of concreting machinery have supplied the trade with well-designed and well-built machines which take the place of hand labor, and which produce a more reliable grade of concrete in an economical manner. The old saying, "What is worth doing is worth doing well," applies in the mixing of concreting materials in a very noticeable way. For if concrete is not mixed well, it is not concrete in the strict sense of the word.

INSPECTION OF CONCRETE MIXING

So vitally important is the mixing operation in its bearing on the quality of concrete work, that inspectors on jobs should have a clear, precise knowledge of their duties, and the fullest possible realization of the great responsibilities resting upon them. While details will of course differ to some extent with the type of work, size of job, and character of mechanical equipment, the following instructions sum up in a general way the duties of an inspector so far as the putting together of ingredients is concerned:

The contractor often desires to measure the sand and stone by wheelbarrow loads. In such cases the inspector will measure the capacity of the barrow used, and determine the size and number of loads required for one batch of concrete, and thereafter insist that the loading conform to this standard size. As a check, the inspector should frequently keep account of the bags of cement and the barrow loads of sand and of stone used during, say, two hours, and measure the quantity of concrete made, and determine from this data the ratio of the materials used. In any case the inspector must make return for the amount of material used during the day, on his daily report, by giving the exact quantities as counted by him both as to bags of cement and as to cubic yards of sand and stone used; and the quantities must not be estimated from calculations based on the concrete laid.

When a concrete mixer is used, the inspector must acquaint himself with the theory and principle of operation of that particular type of mixer, and be able to detect any change in the proportions or uniformity of the mixture at any time.

When the mixer is of the automatic-feed type, the inspector must test it at least once during each day's work, at times unexpected by the foreman, by feeding measured quantities of cement, sand, and stone into the respective hoppers, in the proportion of 1:3:6 or such other proportion as the automatic feeding device is supposed to have been adjusted to. If the mixer is gauged properly and feeding freely, the measured quantities of materials will be exhausted simultaneously. Should some cement be retained in the cement hopper after the sand and stone are exhausted, it is sufficient indication that the mixer is either improperly gauged, or that the cement feed is clogged. Whatever the trouble, it must be corrected before the mixer is allowed to continue.

When the contractor employs a concrete mixer into which the materials are not loaded in batches, the inspector is not, without first carefully testing the machine, to depend for the securing of the proper proportions on the accuracy of the machine gauging or of the proportioning done by the shovelers employed. The materials should be placed in properly proportioned piles, not containing more than 10 cu.

yds. in the case of sand, broken stone, or gravel; and the inspector must see that the machine exhausts all materials simultaneously. Should it be impossible to obtain these results, due to improper piling of material, the inspector should insist on the use of measuring boxes for proportioning the charges delivered to the mixer.

Gravity Distribution of Concrete

One of the most important aids to rapid construction, especially on large building jobs where concrete has to be distributed over large areas, is what is known as **gravity system of distribution.** Fundamentally, this system comprises:

(1) A temporary **tower** equipped with hoist for elevating the concrete. This tower may be built up either of lumber or of steel members, and is firmly guyed to keep it stable and perpendicular. It may be either stationary or portable, in the latter case being mounted on a truck or car on wheels running on a track so that the tower can be moved to various points on the job to facilitate distribution of the concrete as needed.

(2) **Inclined chutes,** made of sheet metal, into which the concrete is dumped from the hoist bucket or hopper on the tower, and which convey it by force of **gravity** alone to the required point of discharge into the forms on the job.

There may be several of these towers, depending on the area covered in the operations; or a main tower of great height may be supple-

mented with one or more auxiliary towers of less height, the latter designed to support the distributing chutes where the concrete has to be placed at long distances from the hoisting tower.

Advantages. There are many great advantages in the gravity system for distributing concrete. Concrete can be mixed at one central mixing plant, and placed as readily and economically at 500 to 800 feet from the mixer as it can be placed close at hand. The expense of building and maintaining runways and their supports is avoided; a clear working floor free from obstructions is possible; and—what is of the greatest importance in the end—the cost of placing concrete is surprisingly reduced. Furthermore, the quality of the concrete is assured, as only concrete which is properly mixed can be handled by a gravity plant.

A few of the points of superiority of this method over the wheelbarrow or cart method are as follows:

The initial set of the concrete takes place in the forms, and not in transport.

A uniform, homogeneous, plastic mixture is obtained, overcoming all tendency to laitance.

The unlimited variation in the design of buildings and engineering structures to which it is adapted.

Saves breakage of hollow tile, and prevents displacement of steel on floor work; also saves concrete from spilling, and the cost of cleaning the floors and beams—which undesirable fea-

tures are unavoidable when using carts or wheelbarrows.

The assurance of deep, narrow walls being perfectly filled.

The handling of large quantities, the output being limited only by the mixing and hoisting capacity of the plant.

With the wheelbarrow, cart, car, or bucket method, the dumping of a large mass is apt to bridge over, or to wash itself when dumping, producing pockets. It is also liable to foam, which gives rise to laitance.

On account of the concrete flowing in a small and continuous stream, this method is as well adapted to pour thin walls and columns in which there is a large amount of steel as for large masses of concrete in dams and abutments.

Operation. The operations of the method are as follows:

The mixing of the concrete in any suitable batch mixer.

The hoisting of the mixed concrete by an automatic dumping bucket in a tower, to an elevated hopper.

The transfer of the concrete to chutes leading from this hopper to the forms.

The method is one of extreme simplicity and of surprising flexibility.

For the successful operation of a gravity plant, one of the essential things is the proper mixing of the concrete. Having given the proper proportions of cement, sand, and gravel, it is

absolutely necessary that enough water should be added to produce a specific gravity such that the rock is held in suspension. The mixture should flow like a thick gravy, with no excess water. In other words, the mixture should have a saturated amount of water, and no more. This particular mixture is surprisingly slippery, having an oily nature, and flows readily around steel.

Many experimental tests, involving an outlay of large amounts of money, have been made to determine the maximum and minimum angles of flow, the rate of flow, and the comparative value of different shapes of troughs and pipes.

Concrete has been run successfully by the gravity method from 7 degrees to 45 degrees with the horizontal, dropping vertically in a closed chute 120 feet into a hopper, and redistributed. The angle which will best fit usual conditions, and the one most generally used by engineers, is about 18 degrees with the horizontal, or an inclination of 1 to 3.

The rate of flow of concrete of the proper consistency in round metal chutes at a grade of 1 to 3, will be about 250 feet per minute; but this will vary through a wide range with differences in the mixture and in the pitch of the chute. It has been found by experiment, that, through a round opening of 7-inch diameter emptying into an 8-inch trough at an inclination of 18 degrees with the horizontal, concrete of good consistency will run at the rate of 132 cubic yards per hour.

Different shapes and sizes of chutes have been experimented with—the flat, wide trough; the V-shaped trough; the U-shaped trough; and pipes from 4 to 10 inches in diameter. The conclusion has been that while, with an ideal, uniform mixture, a 7-inch, round chute may be large enough for the larger sizes of standard mixers, the unavoidable variations from the ideal which mark all construction work make a 10-inch-diameter open-top chute more generally serviceable than one of smaller size and different shape. It has been found that, especially in long-distance spouting, the 8-inch chute will clog, while a 10-inch open-top chute will deliver the concrete in perfect condition at distances of 700 to 800 feet. The opinion has been expressed by engineers, that the only practical limit to the distance at which concrete can be delivered in this chute is the limitation to the height of the elevating tower. The open-top chute is better than the closed chute because the flow of concrete is always under observation, and the chute cannot become clogged by a dry batch beyond easy remedy.

It is sometimes necessary to employ a larger chute than 10-inch where large stones are used with the concrete. Stone or gravel held by a 3-inch ring is too large for a 10-inch chute.

The following are a few essential instructions for operating a gravity plant:

On beginning operations, flush the chutes with a bucketful of water, followed immediately

by a charge of very thin, sloppy grout, and then, as quickly as possible, with a batch of concrete; and maintain as far as practicable a continuous stream of concrete.

The mixture should have the consistency of a thick gravy, the rock being held in suspension; if, when dumping into the bucket, it stands up, it is too thick; again, if it levels off and shows as much as one inch of water, it is too sloppy.

There should be a man in the tower to operate the hopper gate, regulate the flow of concrete through the chutes, and time the discharge so that the stream will be as continuous as possible.

At a shut-down of over 20 minutes, flush the chutes by sending up a bucketful of water. At the end of a day's work, clear out the mixer with two charges of water, and send same through the chutes.

Labor Costs. The labor cost of mixing and distributing concrete by the gravity method will vary from 18 cents to 50 cents per cubic yard. A fair average cost on building construction will be about 35 cents. It has been found that better concrete is obtained by omitting the tamping. The number of men required to distribute concrete after it is mixed and placed in the hoist bucket, will be a hoisting engineer, a man at the receiving hopper, and generally two men at the distribution end of the chute. If the shifts are numerous and cover considerable area, one or two additional men may be required to handle the spouting.

CONCRETE MATERIAL WASHERS

Special machines are built for the washing of sand, gravel, and crushed stone. They operate somewhat after the manner of mixing machines, by agitating the material in an excess of water. In a typical example of one of these power-driven machines, the agitator revolves in a horizontally mounted cylindrical drum.

Modern apparatus for screening and grading sand, gravel, or crushed stone, is also sometimes equipped for washing the material during the process, to remove dirt and all excess of very fine material, the water being applied as the material passes through the screening and separating devices.

A concrete mixer may be used for washing sand and other aggregates. The mixer, in such a case, is simply charged with the material, and then water is turned in until it overflows at the discharge. The machine is then set in operation, and the supply of water kept up, the impurities being carried off in the overflow.

ENGINES, HOISTS, AND ELEVATORS

All the common types of power driving—steam, gasoline, electricity—are adaptable to the operation of concreting machinery. In the majority of cases, however, **steam engines** or **gasoline engines** are employed as the sources of moving power. The detailed description of these necessary adjuncts in building operations be-

longs to the field of Mechanical rather than Constructional Engineering.

In some cases, hoists are adapted to double platform elevator work in which one platform is descending as the other ascends, in addition to having a drum for direct hoist work run independently of the cable sheave that operates the

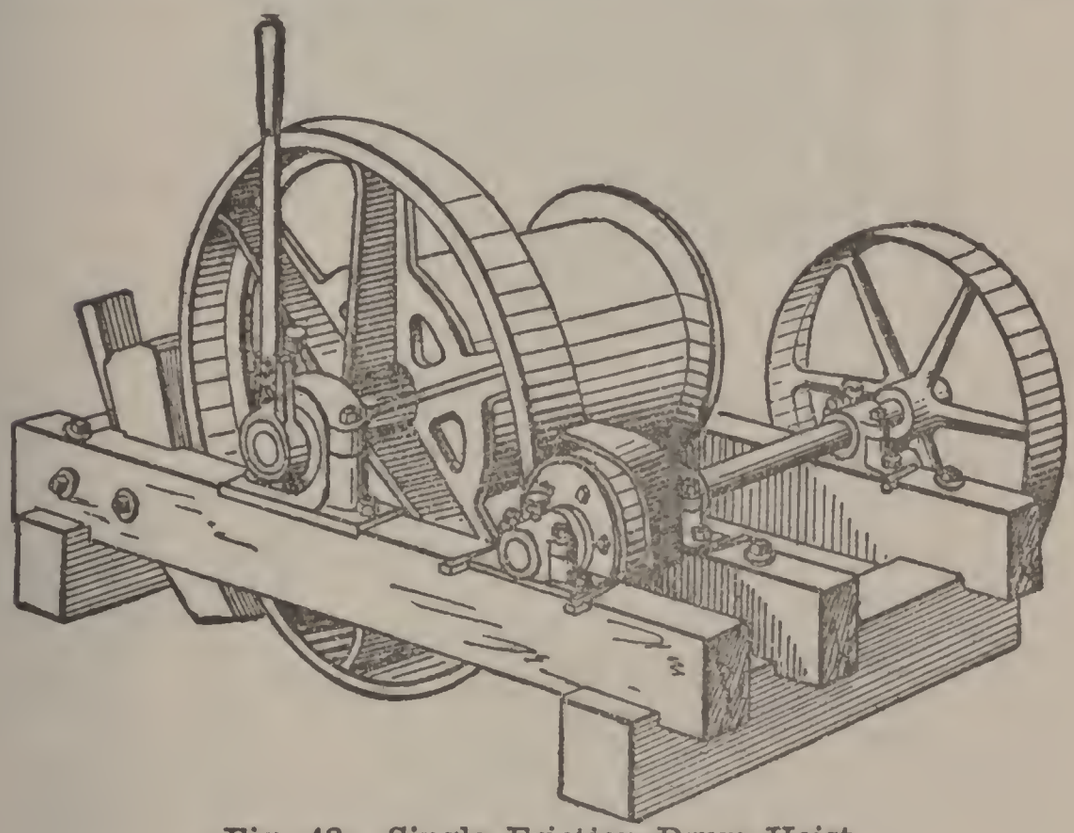


Fig. 48. Single Friction Drum Hoist.

elevator platform. With such machines, material can be raised or lowered independently of the elevator—an important feature in some circumstances.

The installation for outside work shown in Fig. 44 includes a power mixer with elevator for automatically hoisting and dumping the charging bucket; also an electrically operated extension hoist, with automatic tilting skip or bucket

discharging by gravity on the different floors as the structure rises. The concrete is discharged into a bin having a gate operated by hand-lever as shown, whereby the supply to the carts or

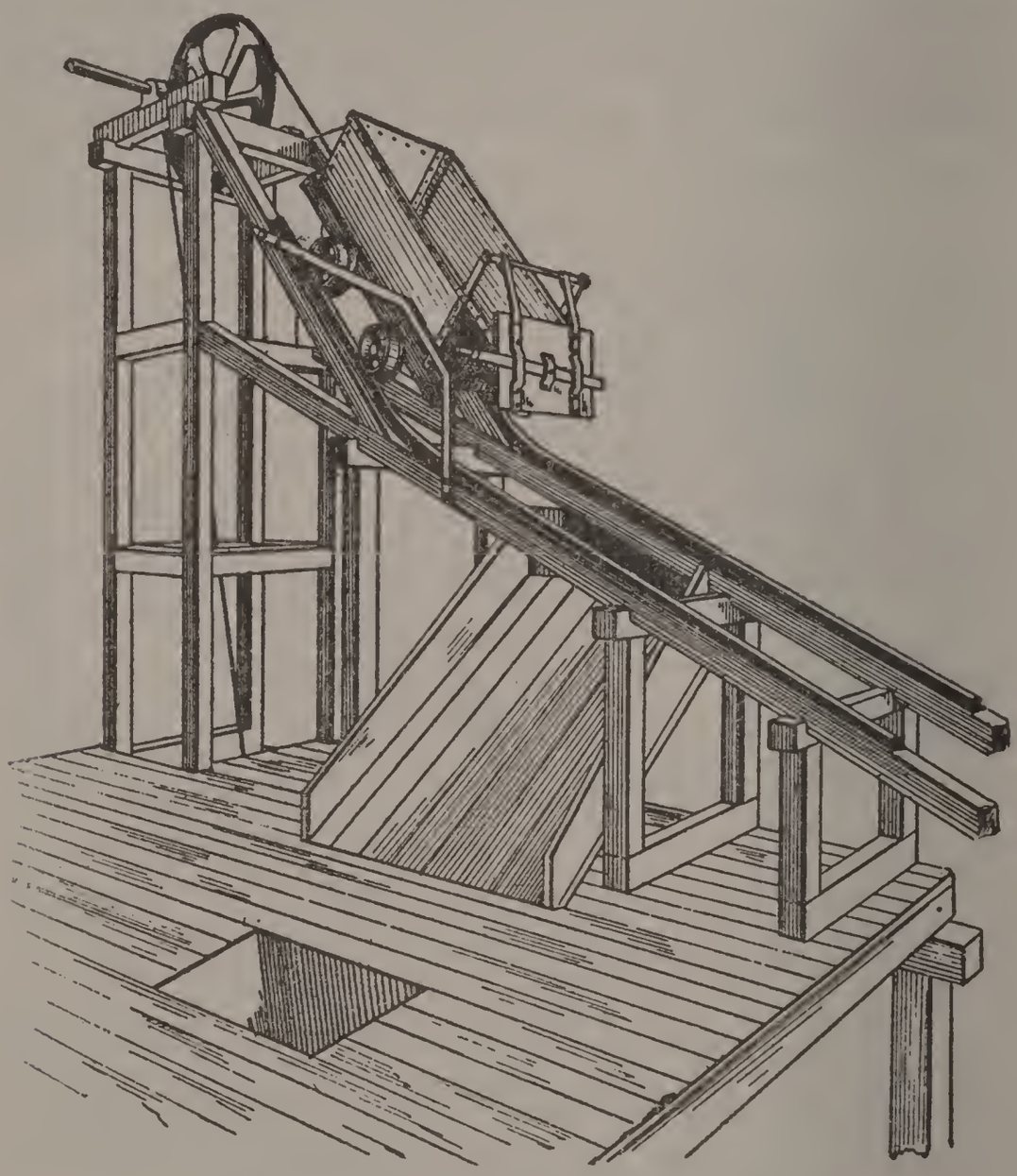


Fig. 49. Automatic End-Dump Car.

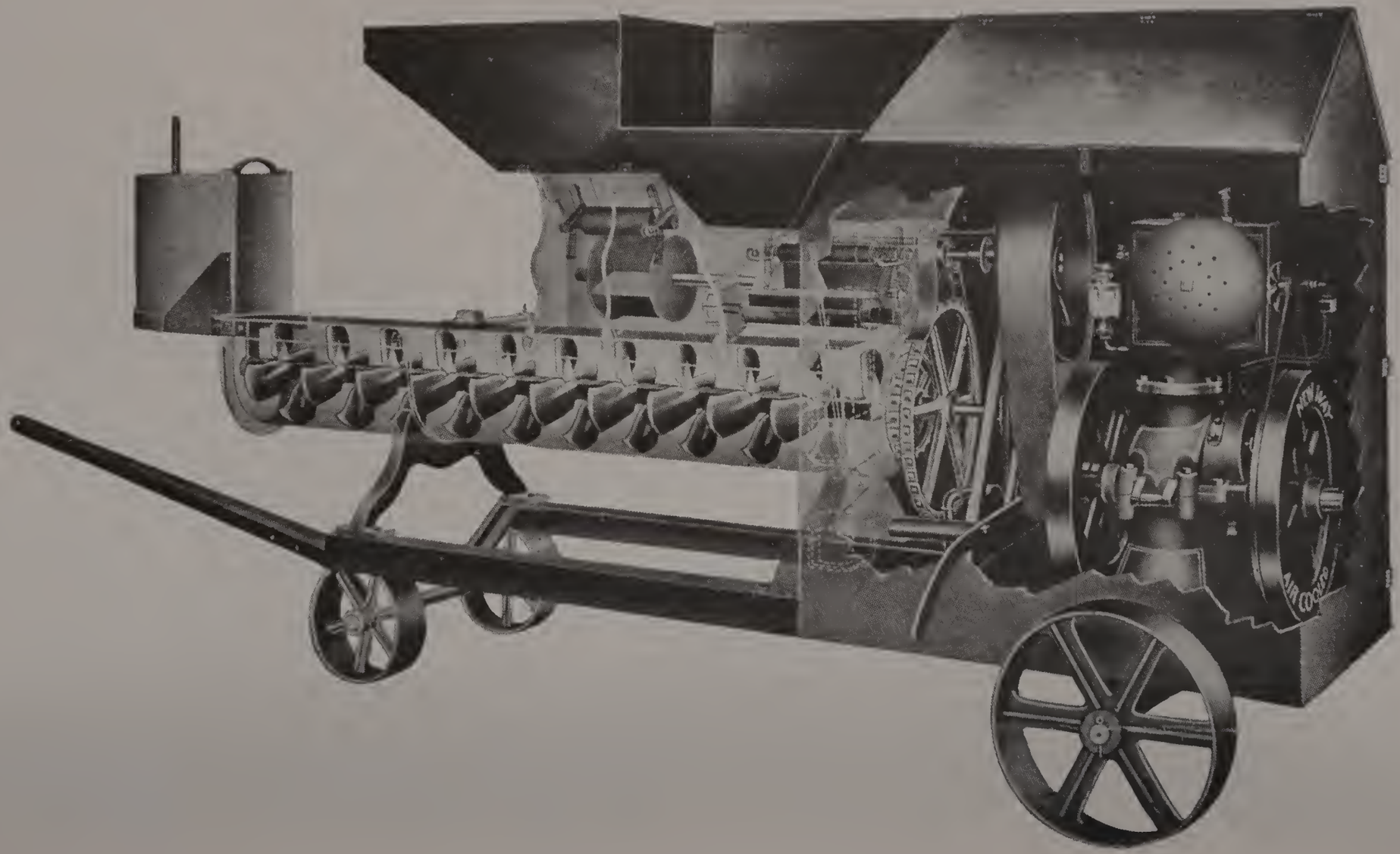
wheelbarrows is controlled. The skip automatically rights itself on its return.

Other installations of this same type are adapted to inside work. In these cases the elevator frame must either be fastened to the struc-

Mounted on Trucks with Steam Power.

Mixer with Power Side-Loading Equipment.

INVOLUTE CURVED DRUM BATCH MIXER.



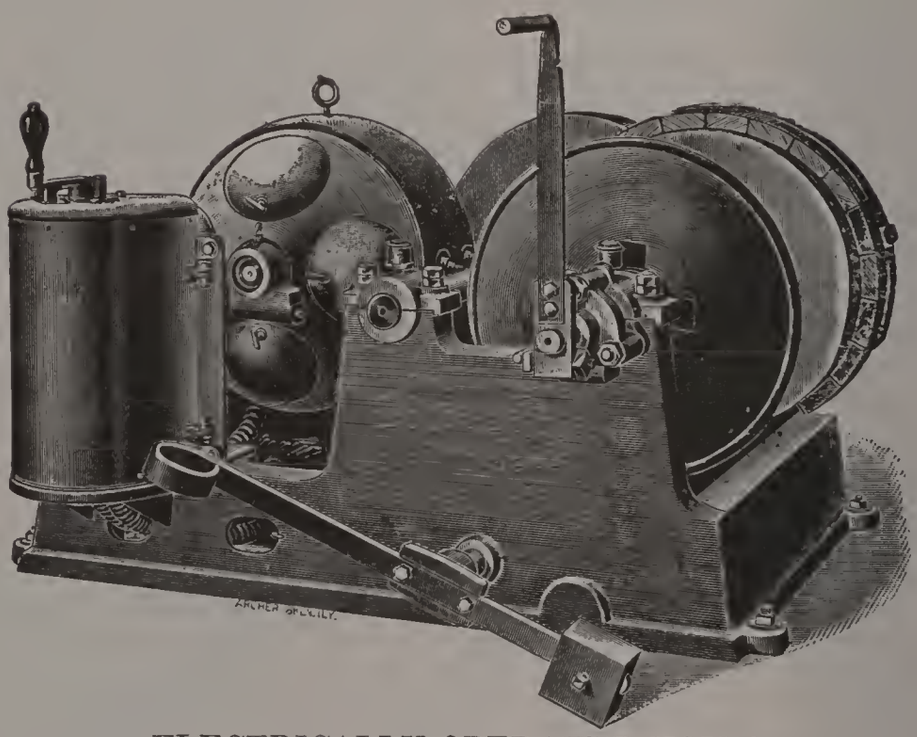
PHANTOMIZED VIEW OF AN AUTOMATICALLY PROPORTIONING CONCRETE MIXER.

CONCRETE MIXER EQUIPPED WITH ELEVATING CHARGING BUCKET AND WATER-MEASURING TANK.

ONE TYPE OF AUTOMATIC WATER-MEASURING TANK.

STEAM HOISTING ENGINE.

For derricks, pile-drivers, cableways, etc.



ELECTRICALLY OPERATED HOIST.

ture or encased in a supporting frame, which may be built of scrap lumber or other cheap material; also, it is sometimes necessary to guy the top section of the frame into place.

The mechanical aids employed in the handling and depositing of wet concrete, the conveyance of concrete products (such as blocks) to and from curing and storage rooms, etc., include a large number of special devices intended to lighten labor, promote efficiency, and lower cost—such as special types of light steel **wheelbarrows** and **hand carts,** self-dumping **steel buckets, cars,** and **wagons; sectional rack cars,** for blocks, etc. Some buckets discharge automatically by tilting; others, by "bottom dumping;" while some of the latter are so constructed that their discharge may be controlled, the doors being opened or closed under load, so that concrete can be discharged directly from the buckets into forms. Some cars have an "end dump," as in the example illustrated in Fig. 49; others, a "two-way rocker dump," discharging by tilting to either side; while still others have the car body mounted on a sort of turnstile on the truck, swinging around and dumping at any point in a complete circle—an "all-round dump."

Special cars for handling concrete blocks, sills, and other moulded shapes are built of channel or angle steel, with removable decks so that the load may comprise one, two, three, or more tiers.

CONCRETE BLOCK MACHINES

Concrete blocks in various forms are coming to be recognized more and more as an important factor in building construction. There are comparatively few buildings erected to-day into the construction of which concrete molded shapes, in some form or other, do not enter. Even where the building is not by any means to be classed as a block structure, we find these shapes commonly used in certain special locations. Their strength and fireproof qualities, their durability under abrasion and severe climatic conditions, their adaptability to harmonious combination with other structural materials, together with their cheapness of cost, have commended them to very common acceptance for use as water-tables and belt-courses, door and window sills and lintels, etc.—for which uses they have very largely supplanted the old-time cut stone.

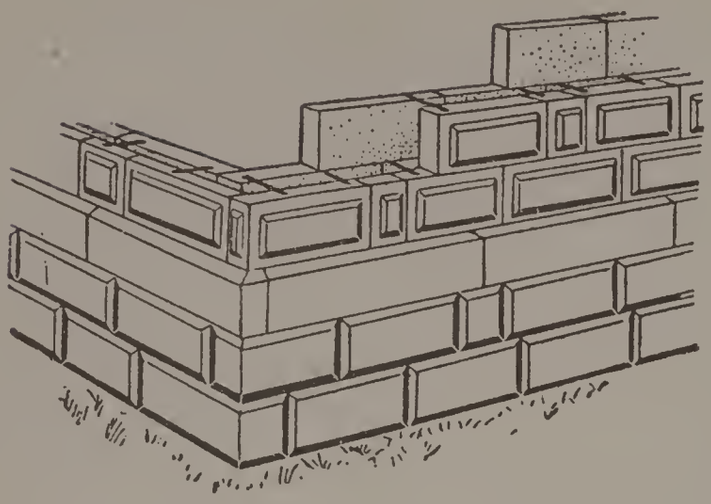
In ornamental shapes for garden, lawn, and landscape decoration, as columns, capitals, pilasters, brackets, etc., for the exterior and interior embellishment even of the most elaborate structures, they are also coming into more and more extensive use.

The question of their complete function and limitations in building construction, as in the erection of houses built entirely of blocks, is one on which opinions differ considerably. The once common complaint of dampness and con-

sequent discomfort and unhealthfulness as characteristic of the block structure, had its basis in the imperfect work that marked the early, unfortunate attempts at this form of construction. But with up-to-date, improved machinery for making blocks, with our present advanced knowledge of the essential requirements in proportioning and mixing ingredients and in molding and curing, and with modern methods available for rendering all concrete work as truly damp-proof and waterproof as work in any other material can possibly be made, there is no longer any foundation for this complaint.

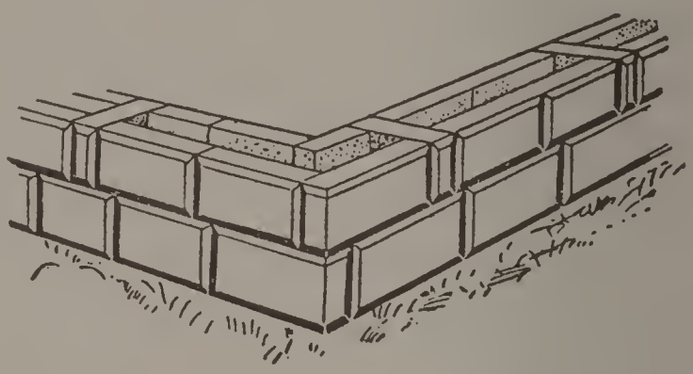
There is, moreover, no doubt that with the honest avoidance of all mere attempts at imitation, with the use of appropriate faces and finishes, with due consideration of the possibilities of pleasing combination with other materials and of harmonious adaptation to surroundings in the selection of attractive outlines and color schemes, concrete blocks do lend themselves admirably to truly artistic effects in building design.

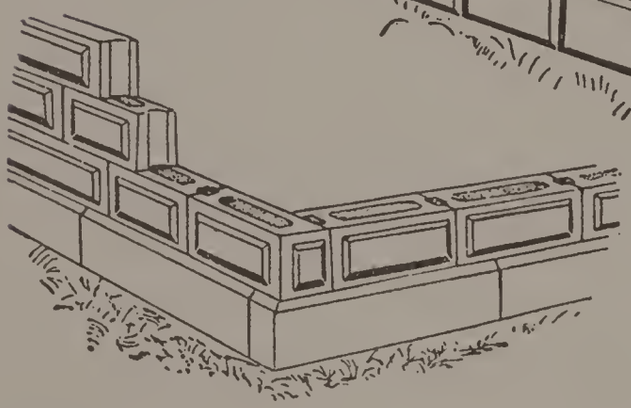
The block industry has grown to such an extent that the molded concrete units are furnished to a community by a local manufacturer, and are recognized as a standard type of building material. Although we have used the term "manufacturer," we have here used it in the broad sense which accompanies the use of concrete itself. Concrete is a material which permits of great flexibility as to form of construc-



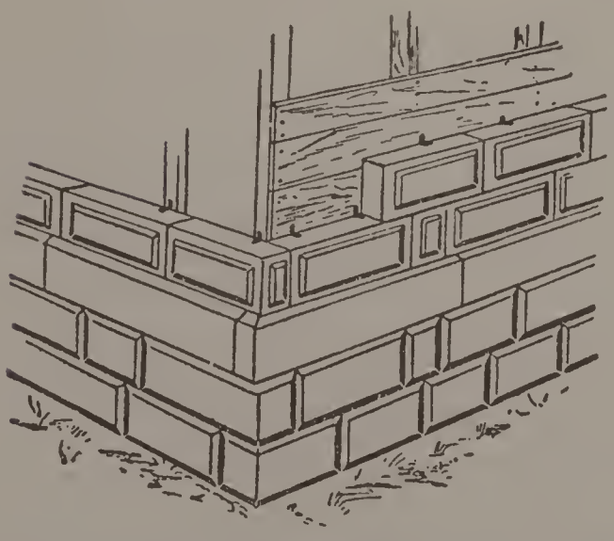
Two-Piece Wall
Tied with Metal

Two-Piece Wall
With Header Bond





Regular Hollow Wall
with Water Table



4-inch thick Veneer Block
for Frame Building

Fig. 50. Typical Examples of Concrete Block Wall Construction.

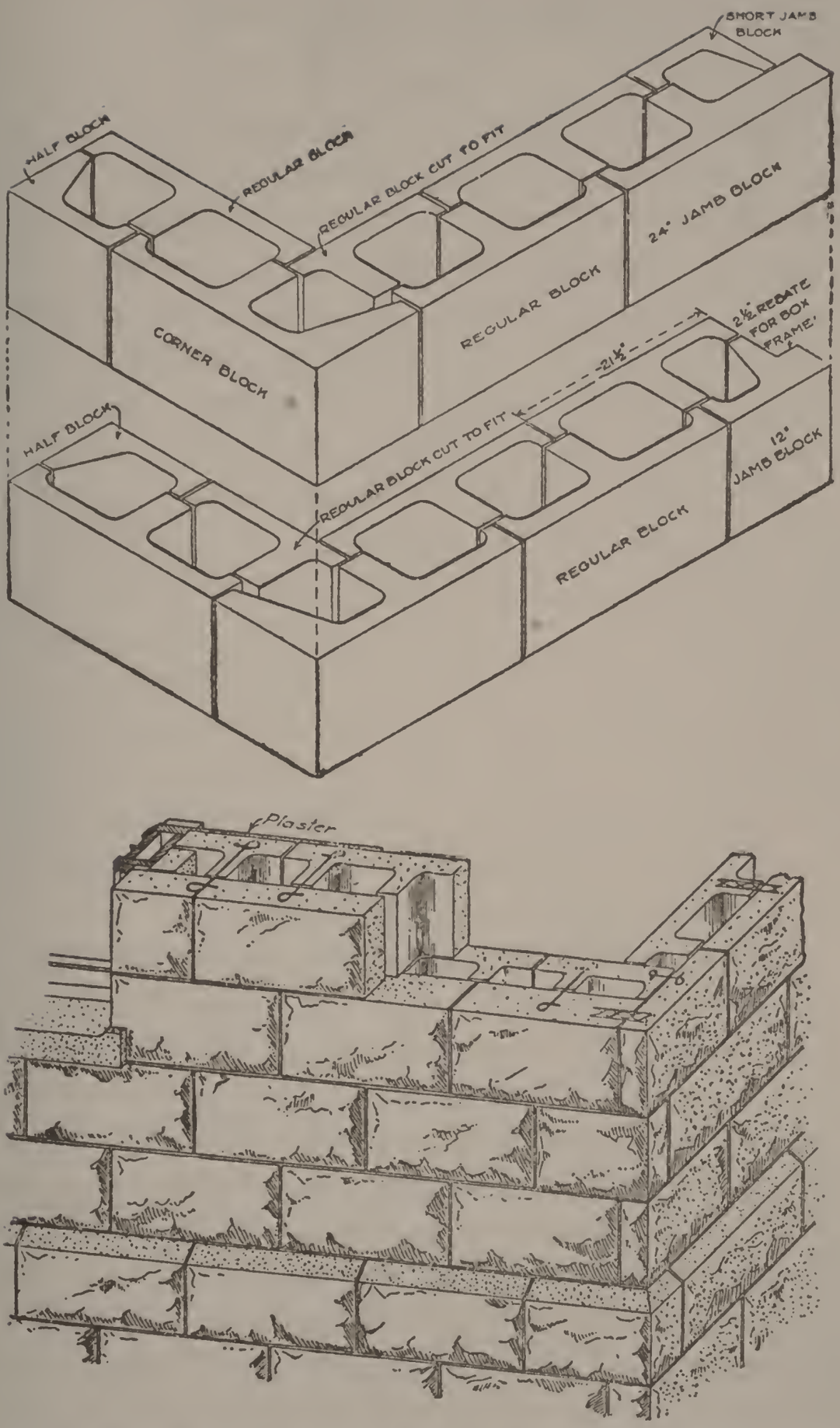


Fig. 51. Two Methods of Hollow-Wall Concrete Block Construction.
Lower figure shows a veneer wall.

tion and purpose of application. The ease with which it is handled, and the simplicity of the equipment needed, allow the farmer with a single block machine to become a manufacturer for his community in the same sense that the man with a more extensive plant may supply the trade of the small city or town. Machines for making concrete blocks are not expensive, and the additional equipment needed is not great.

Advantages of Block Construction. One of the advantages of the use of concrete in the form of blocks for house construction, is that a few blocks may be made at a time, and, after proper curing or hardening, be put aside until needed. In this way the actual making of the blocks may extend over several months; but the walls of the building can be put up in a very short time. Such a procedure would not be advisable in the case of monolithic or poured walls.

Other advantages claimed for concrete block walls are as follows: (1) Their hollow shape allows a saving in the amount of materials used for a given thickness of wall; (2) the cost of laying concrete blocks is less than for brickwork; (3) a wall properly constructed of a good grade of concrete blocks is as strong as or stronger than a brick wall of the same thickness; (4) the air-space in the concrete blocks acts as an insulating medium, thereby making the house cooler in summer and warmer in winter; and (5) the ease and rapidity with which a block wall can be constructed.

Types of Blocks. Blocks may be made **solid** or **hollow.** Some typical methods of using them in house building are illustrated in Figs. 50 and 51. In wall construction, solid blocks are laid in single courses for veneering, being bonded to the framework, the interior of the wall being furred, lathed, and plastered. **Veneer blocks** are cast thin and of solid cross-section. Where the wall is built entirely of concrete blocks, these, if solid, are laid in two courses, with an intervening air-space for insulation against cold and dampness, the two courses being bonded together either with metal ties or by the use of bonding headers or by means of concrete lugs on the blocks. With the hollow block, on the other hand, the insulating air-space is directly provided in the interior of the block itself; and in such cases, if proper care has been taken in the manufacture and laying of the blocks, or in the use of a reliable waterproofing process, or in both, furring and lathing may be dispensed with, and the plaster applied directly to the inner surface of the wall.

Hollow blocks are sometimes distinguished as **one-piece blocks** and **two-piece blocks** or **continuous air-space blocks.** In the "one-piece" type, the air-space represents the void that was occupied by the core around which the block was molded. In the "two-piece" type, the insulating dead air-space may be obtained by embedding pieces of metal in the block itself to tie together the outer and inner portions; or it may

be formed through the shape of the pieces themselves, which, in different commercial types of blocks, are made in a variety of forms resembling more or less closely in section the steel shapes known as channels, angles, and tees (see Figs. 25 and 51).

Sizes of Blocks. The sizes of concrete blocks vary with types of blocks and kinds of block machine used. Manufacturers furnish equipment for making a given size or range of sizes of blocks on the same machine. Common sizes of hollow blocks are made in heights of 4, 6, and 8 inches; in widths of 6, 8, 10, and 12 inches; and in lengths of 16, 20, and 24 inches. Fractional lengths of each of these sizes are made for use where needed in lengths of wall which are not even multiples of the block length used.

Solid blocks for veneer work are commonly made in the same heights and lengths which are given for hollow blocks, but in widths varying from 2 to 8 inches. Fractional blocks of this type are also used.

Blocks of special size and for special purposes are advertised, and are described as to shape and dimensions in the catalogues of the block machine manufacturers. Corner blocks, jamb blocks, special pier blocks of various shapes, angle blocks, joist blocks, nailing blocks, window blocks of several types, gable angle blocks, water-table blocks, panel belt blocks, circle blocks, return corner blocks, chimney blocks, and many other shapes of block, are made in sizes

and fractional lengths ready to set directly in place in any given case.

Manufacture of Blocks

Materials Used. Blocks may be made from Portland cement and sand; Portland cement and gravel or broken stone; or from a combination of these materials. Sand mixtures are used to a considerable extent on account of the cheapness of sand and the ease with which it is obtained. Gravel or broken stone mixtures produce a better grade of concrete, and require less cement. An aggregate with particles of varying size gives better results than one of uniform-sized particles. Fine sand is not desirable. Gravel may be used as it occurs, if the mixture does not contain too large a proportion of fine particles or pieces of material too large for the work. It is better to screen gravel and then re-mix the fine and coarse particles in a well-balanced manner. All aggregate should be free from dust, loam, and foreign matter.

The cement should be a good grade of Portland cement. The sand should be a siliceous material, clean, gritty, and of a size which will pass a ¼-inch mesh sieve. The coarse aggregate should be clean broken stone, free from dust; or clean screened gravel. These materials should be of a size such that they will pass through a ¾-inch mesh screen and be caught on a ¼-inch mesh screen.

Proportions. For exposed exteriors or bearing walls, the proportions are as follows:

(a) Concrete hollow blocks, machine-made, using semi-wet concrete or mortar, should contain 1 part cement, not to exceed 3 parts sand, and not to exceed 4 parts stone. When the stone is omitted, the proportion of sand should not be increased, unless it can be demonstrated that the percentage of voids, and tests of absorption and strength, allow in each case of greater proportions with equally good results.

(b) When blocks are made of slush concrete, in individual molds, and allowed to harden undisturbed in same before removal, the proportions may be 1 part cement to not to exceed 3 parts sand and 5 parts stone; but in this case, also, if the stone is omitted, the proportion of sand should not be increased.

It is claimed that hydrated lime added to the concrete mixture will increase the density of the blocks and produce a lighter colored concrete. The amount added varies from ¼ to ½ the volume of cement used.

Amount of Water. The amount of water used will vary with the type of mixture employed and with the process of manufacture. Dry mixtures are necessary for rapid molding and early handling. If blocks are made too dry, they will remain soft and weak in spite of after-treatment. Too wet mixtures stick to the machine parts unless molded in forms and al-

lowed to remain in these forms until the cement has commenced to set. The concrete should be allowed all the water that it will stand, on account of the virtue of water itself as a waterproofing agent.

A practical way of determining the proper degree of moisture is to squeeze some of the mixture in the hand. If the mass holds its shape upon relieving the pressure, it may be used; otherwise it is too dry. It should hold together when laid on the other hand, and should but slightly moisten this hand when squeezed in it.

Blocks molded by pressure may be made of a medium-wet mixture, while poured blocks may be of a slushy consistency.

Systems of Block Making. There are two systems of block making. They differ in the consistency of the concrete used. They are:

1. Blocks tamped or pressed from semi-wet concrete and removed from the mold.

2. Blocks poured or tamped from wet concrete and allowed to remain in the mold till hardened. Most of the blocks on the market are made by the semi-wet method, in machines from which the cores are removed and the side plates taken away as soon as the block is formed. Then the block is lifted from the machine.

The various styles of blocks are rock-faced, granite- or other special-faced, plain, tool-faced, fluted, grooved, ashlar, and imitation cobblestone.

The molded blocks are taken from the machine on what is known as a **pallet.** This consists of a piece of flat board or sheet metal about the area of the block, and sufficiently firm to prevent warping or binding. Where many blocks are to be made at a time, a great number of these pallets will be needed, since a concrete block should never be taken from its pallet for at least 24 hours after removal from the block machine. All chipped or imperfect blocks should be rejected at this time, and thrown back for remolding.

Molding blocks by pressure alone is generally confined to blocks where the pressure may be applied to surfaces of no great thickness. In the ordinary block, the mold should be filled a little at a time, and the material thoroughly tamped after each filling. At least four fillings and tampings should be given each block.

Curing of Blocks. After the blocks come from the machine they must be treated in such a manner as to allow the cement to develop its full strength throughout the body of the block. Cement requires moisture in order that it may harden, and unite the particles of the aggregate into a solid mass. Drying-out of concrete does not necessarily mean hardening. Therefore this process of curing is one of the most important steps in block manufacture.

All blocks made from medium-wet or medium-dry mixtures should be made under cover, and protected from the sun, from air currents,

and from frost, until thoroughly hardened. After the blocks are taken from the machine, they should be taken to a cellar or closed shed for treatment. As soon as the concrete has set so that it will not wash away easily, the blocks should be sprinkled gently. This may be done after the block is from 4 to 12 hours old. From this time, the blocks should be sprinkled evenly and gently two or three times a day for from 7 to 14 days. Plenty of water should be used, and blocks should be placed or piled in such a manner as to receive moisture equally on all sides. Blocks which turn white in spots indicate poor curing. The slower the drying of the blocks, the harder will they become.

Concrete blocks made from dry mixtures require longer curing and more frequent sprinkling than those made by the wetter processes. Dry-process blocks may require two or three weeks of curing and sprinkling in order to obtain desired results.

A damp atmosphere may be aided by the use of a sand floor in the curing room, or by spreading over the blocks wet canvas, burlap, hay, or other covering which will retain the moisture.

Care should be taken in cold weather to prevent the blocks from freezing. Cold delays the setting of concrete; freezing may ruin the face coating of the blocks; while alternate freezing and thawing may spoil the entire block. Blocks should be protected against freezing for at least 10 days after molding.

Steam Curing of Blocks. Steam rooms are often used in the curing process. It is claimed that blocks have been steam-cured and ready for use 48 hours after molding. It is advisable to allow blocks which are to be cured by the steam process to harden for about 24 hours in moist air before subjecting them to the steam treatment.

Blocks with Special Facing. Concrete blocks are often coated or faced with a special mixture on the parts which are exposed to the weather. This special facing is of a richer mixture than the body of the block, and is used either to improve the appearance of the block or to increase its density and add to its water-resisting qualities. The thickness of this facing varies from ¼ inch to 2 inches, but ½ inch is a common thickness. The mixture of materials used in this coat varies from 1 part Portland cement and 1 part sand or crushed aggregate, to a 1:3 combination. The use of special or colored aggregates in this coating makes possible a degree of finish on a concrete wall which is not to be found in any other type of construction. This finishing coat may be placed on the block during the process of manufacture, or may be put on as a stucco coat after the wall is in place. Where a stucco facing is to be placed on blocks, it is better to use a type of block which has a rough or corrugated surface.

Waterproof Qualities of Blocks. We have already referred to the use of rich coatings on exterior surfaces of blocks, and also to the use

of hydrated lime, as means of increasing the density and water-resistance. There are two things in this connection which cannot be brought to notice too strongly: First, the use of a well-graded mixture of cement and aggregates; second the need of water in mixing and

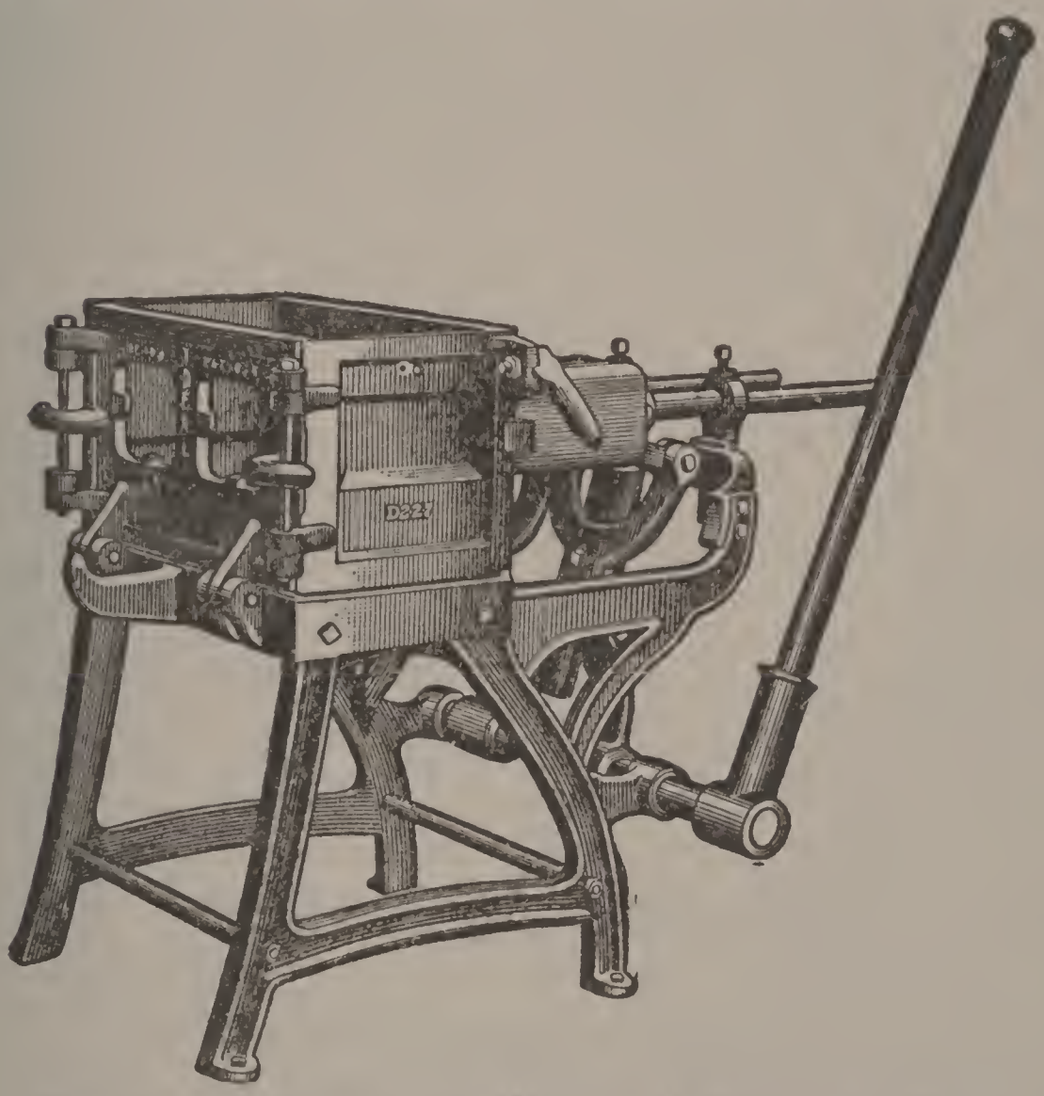


Fig. 52. Concrete Block Machine of Face-Down Type.

curing. A block made of proper materials and provided with a rich facing coat, should be impervious to water. There are many waterproofing compounds of a reliable nature on the market, which may be used as an additional safeguard.

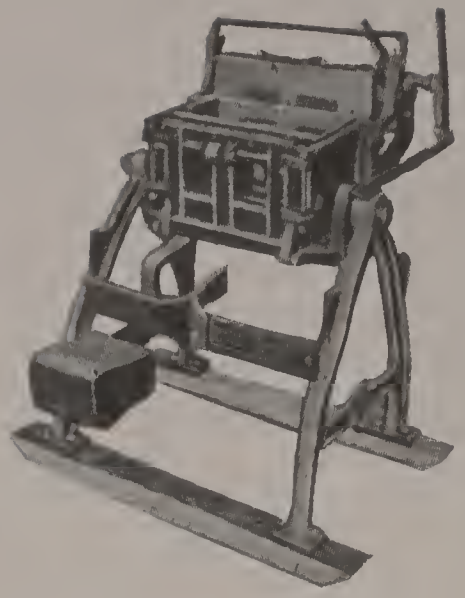
Kinds of Block Machines. There are two general types into which concrete block machines are classified—namely, **vertical-faced machines** and **face-down** or **horizontal-faced machines.** These names indicate the position occupied by the face of the block during the molding process. In the "face-down" or "down-face" machines, the face-plate forms the bottom of the mold; in the other type, this plate is held in a vertical position. The face-down machine is the more easily adapted to applying specially treated faces to blocks. If a vertical machine is used, the special facing (consisting simply of rich mortar, which may be colored, waterproofed, etc.) is placed while the mixture forming the body of the block is kept back by a parting plate or other device. In the face-down machine, the facing can be placed directly in the bottom of the mold, and the coarser body mixture be placed above it.

Block Construction

The hollow-wall type of construction where one-piece hollow blocks are used and the continuous air-space allowed by the use of a two-piece block, aid in preventing dampness within a structure built of dense waterproof blocks.

Mortar for Block Construction. The mortar used in laying concrete blocks in wall construction may be composed of 1 part Portland cement, 3 parts sand, and 1 part thoroughly slaked lime.

FACE-DOWN BRICK MACHINE

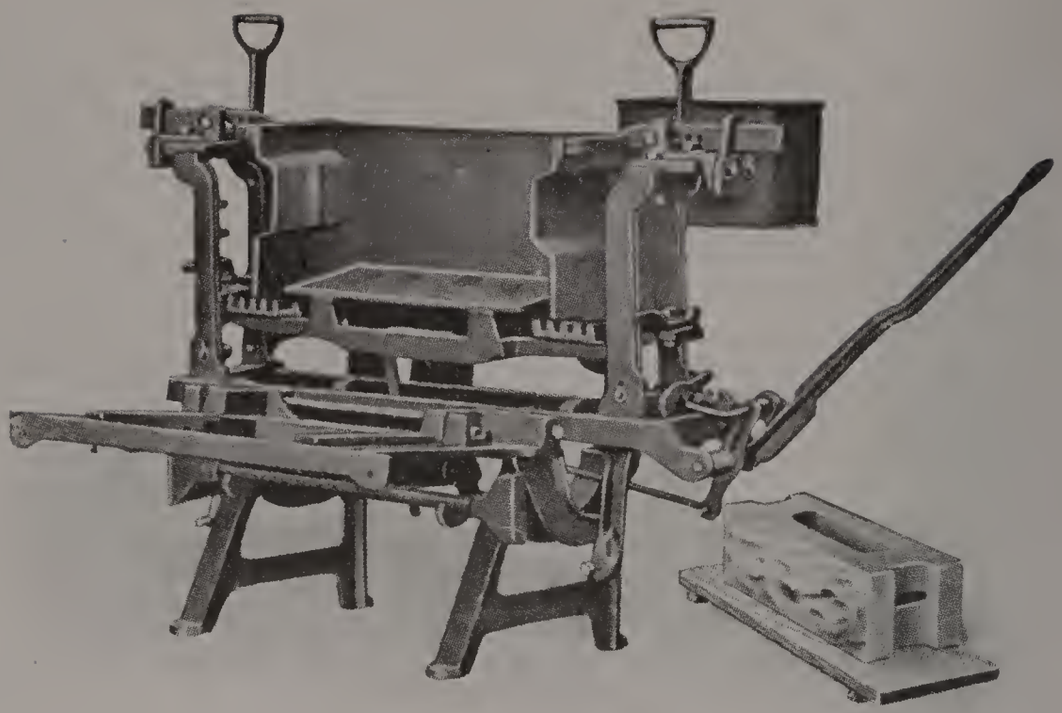


FACE-DOWN BLOCK MACHINE.

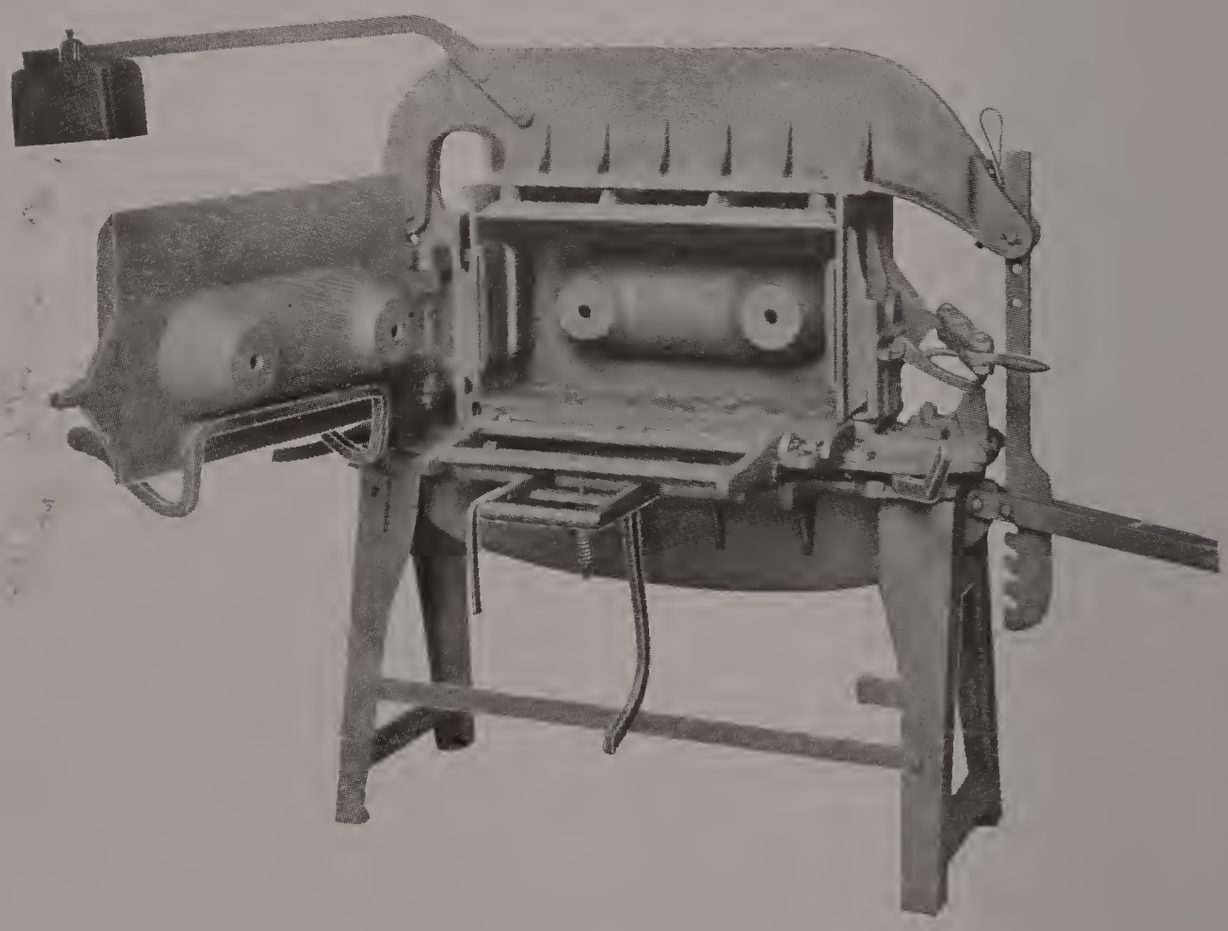
COMBINATION CONCRETE BLOCK MACHINE.

Adaptable to making either face-down, side-face, or two-piece blocks. Blocks are removed with the protecting mould.

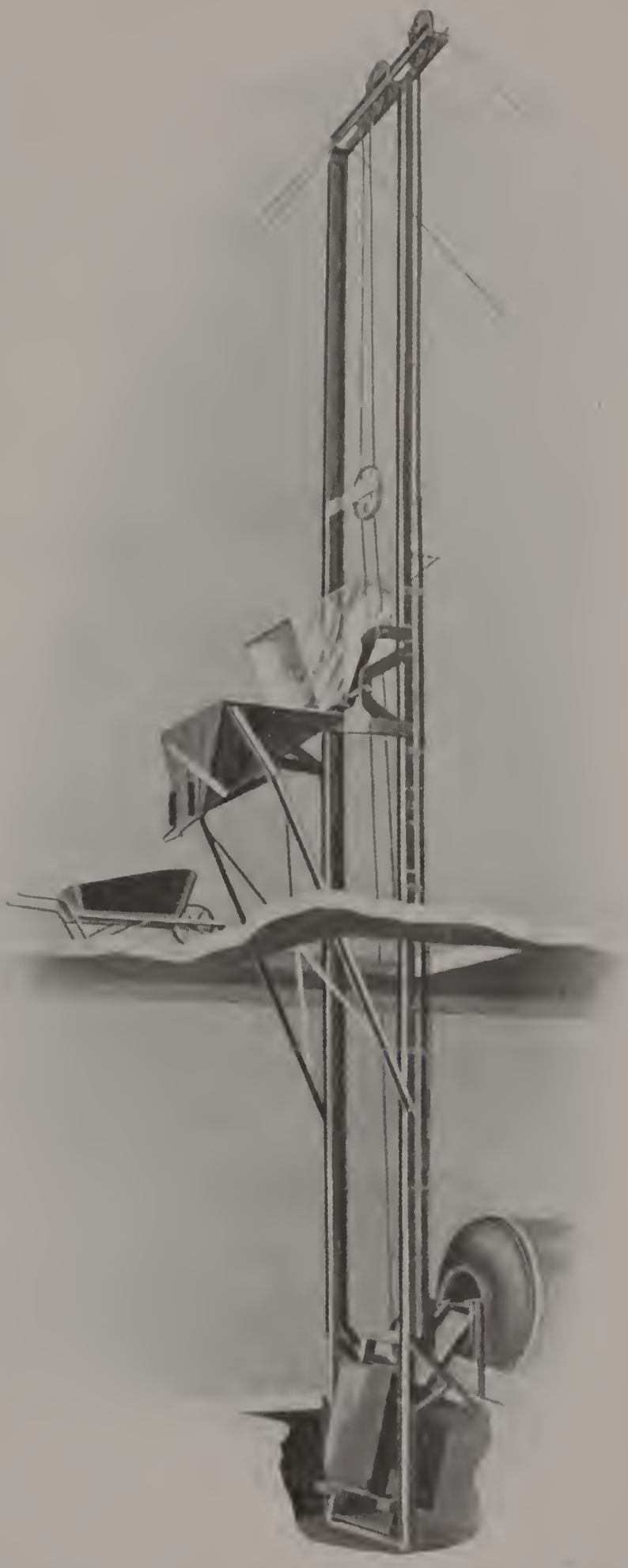
BRICK MACHINE.



AUTOMATIC FACE-DOWN BLOCK MACHINE.



FACE-DOWN HOLLOW BLOCK PRESSURE MACHINE.



CONCRETE HOIST WITH AUTOMATIC BUCKET-DUMPING DEVICE.

AUTOMATICALLY DUMPING CONCRETE HOIST OPERATING INSIDE OF BUILDING.

This should be mixed to a plastic consistency, but should not be too thin.

Thickness of Mortar Joints. Mortar joints in block work may be made from ⅛ to ¼ inch in thickness, but should be of even thickness over the whole surface of the block. Joints which are of unequal thickness may prevent an equal distribution of load on the surface of the blocks, thereby causing a bending action and probably producing cracks in the wall.

All joints should be formed by "buttering" the mortar on the ends of the blocks before laying. The block should then be laid in mortar and worked down to place. End joints should not be left open until after a wall is completed, since, when joints are filled at a later time, the mortar may shrink and fall out, thus leaving openings through the wall.

Joints may be laid with colored mortar, if desired.

Foundations. Foundations for concrete block buildings do not differ from those used with poured or monolithic walls. The footings for all residence or building work should be made of solid concrete; but the basement walls may be either of poured concrete, or built up of blocks. Poured walls are recommended in soft or damp soils, or where water pressure is likely to be encountered.

Basement walls of block work should be made of a heavier grade of blocks than used in the wall above. We believe that monolithic work will

give more satisfactory results for locations below grade line.

Types of Wall Construction. Walls for dwellings may be built from either the one-piece solid or hollow blocks, or from two-piece blocks. One-piece solid blocks, or veneer blocks, are used to a considerable extent, backed up by frame or brick construction. Figs. 25, 50, 51, and 53 show different types of walls built from the various classes of blocks.

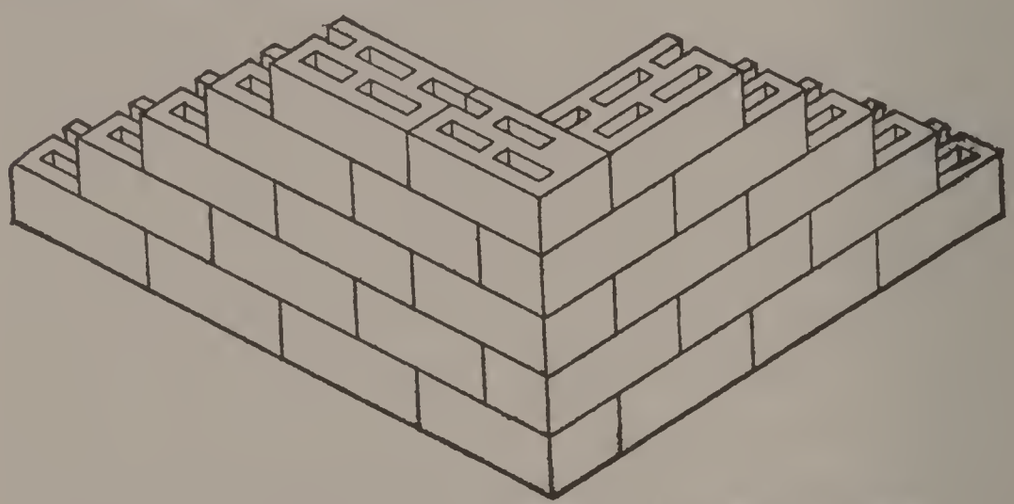


Fig. 53. Wall Built of Double Air-Space Blocks.

Where hollow one-piece blocks are used in wall construction, specifications often insist that the hollow space in blocks used for bearing walls shall not exceed the percentage given in Table XXIII, for different heights of wall; and in no case shall the faces or webs of the blocks be less in thickness than one-fourth of their height.

TABLE XXIII

Percentage of Air-Space in Hollow Blocks

Stories	1st	2d	3d	4th	5th	6th
1 and 2	33	33				
3 and 4	25	33	33	33		
5 and 6	20	25	25	33	33	33

TABLE XXIV

Thickness of Block Walls at Different Stories

Stories	Thickness of Wall, in Inches			
	1st	2d	3d	4th
1	8	..	..	..
2	10	8	..	..
3	12	10	8	..
4	15	12	10	8

The thickness of exterior or bearing walls is often regulated by building ordinances. Table XXIV indicates thicknesses which may be used with safety when there is no ordinance specifying required dimensions.

Where two-piece blocks are used, the wall really consists of two separate walls built from solid concrete blocks tied together by metal ties built into the block during casting, or joined by a concrete web and metal ties. Special veneer blocks may be used, with a rough backing block. These facing blocks are joined to the backing by the use of metal ties placed between the separate courses of blocks, or by bonding in headers between the two parts of the wall every fourth or fifth course.

The two-piece block wall—or walls in which the face layer of material is entirely independent of that part which forms the interior or room side of the wall—provides a means of obtaining a dry residence without extreme precautions in waterproofing. The continuous air-space in such walls allows the removal of moisture from the walls, and prevents transmission of both heat and moisture from wall surface to wall sur-

face. Special galvanized metal ties may be obtained on the market for use in bonding this type of wall.

Block walls constructed of roughly made blocks with rough corrugated faces, give good satisfaction when covered with a dense coating of waterproofed stucco finish. This type of wall is shown in Fig. 54.

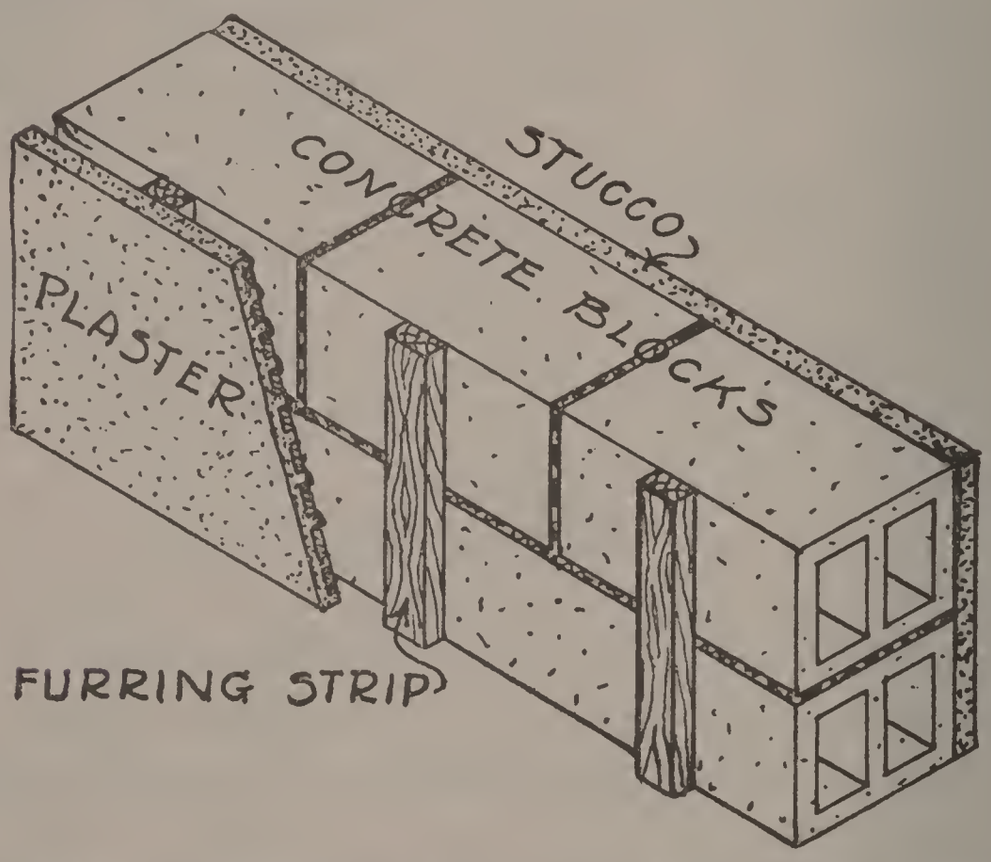


Fig. 54. Concrete Blocks for Use with Stucco Finish on Wall.

If only the face of a wall is of concrete blocks, and the backing is of brick, the face must be bonded to the brick within with headers projecting 4 inches into the brickwork, preferably every fourth course being a header course, or with approved metal ties. The brick backing must be at least 8 inches thick.

Party walls should not be constructed of hol-

low concrete blocks. If used, all spaces should be filled solid with concrete.

Wherever walls vary in thickness at different stories, the top course of the thicker wall should be made so as to afford a full, solid bearing surface for the webs or walls of the blocks above.

Loading of Walls. No block wall, or any part of one, should be loaded to an excess of 8 tons per square foot of superficial surface area of top of block. This should include the weight of the wall above. No blocks should be used in exterior or any bearing walls unless such blocks show an average crushing strength of at least 1,000 pounds per square inch of area at the age of 28 days, no deduction for spaces being made in figuring area of block.

No blocks which are cured by sprinkling should be loaded until two weeks after making, and in many instances 28 days will be needed for the block to acquire the degree of strength necessary for use. Blocks three or four days old should not be placed in walls.

Supporting Girders or Joists. Special blocks for use where girders or joists are to extend into a wall are shown in Fig. 55. It is not considered to be good practice to hang joists from hangers attached to the interior web of the blocks; but all hangers and joists should have as wide a support as possible. One specification demands that where girders or joists rest upon walls so that there is a concentrated load of over 2 tons

on the block, the blocks supporting the girders or joists shall be made solid for at least 8 inches from the inside face. Where such concentrated loads exceed 5 tons, the blocks for at least three courses below, and for a distance extending at least 18 inches each side of the girder, should be

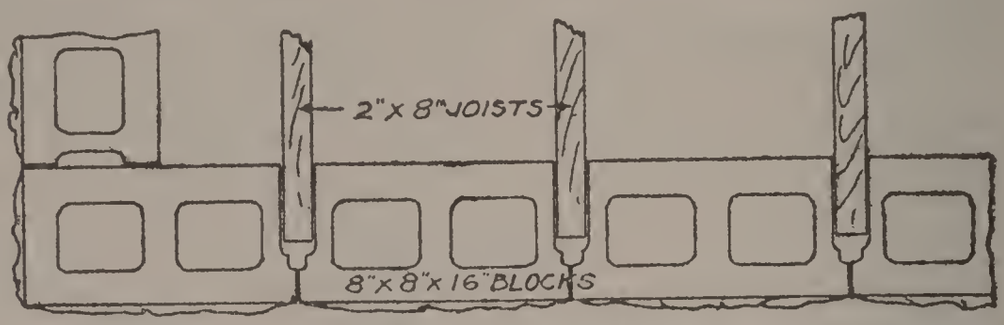


Fig. 55. Method of Supporting Floor-Joists by Use of Special Joist-Blocks.

made solid for at least 8 inches from the inside face.

Sills and Lintels. Concrete sills and lintels may be cast in the same manner as blocks, but should aways be made of a dense, rich grade of concrete, and thoroughly reinforced with steel rods where heavy loads are to be carried or where long spans are needed. For lengths under 3 feet, the reinforcement is often omitted; but it is on the side of safety to include it. The size of rods needed will depend upon the load to be carried and the length of the member. These rods are usually placed about 1 inch from the bottom of the member. Practice often demands that lintels over 4½ feet in length shall rest on solid blocks for at least 8 inches from the face next the opening, and for at least three courses below the bottom of the lintel.

Fastening Woodwork. Special blocks for use around openings such as windows and doors may be cast in the same manner as any blocks. Some of these blocks are recessed and arranged to hold this trim, while others are provided with spaces for wood nailing strips, or have wood plugs cast into the concrete. Details of framing for openings in block walls are treated below.

The roof structure may be fastened to a plate which is held onto the wall by bolts embedded

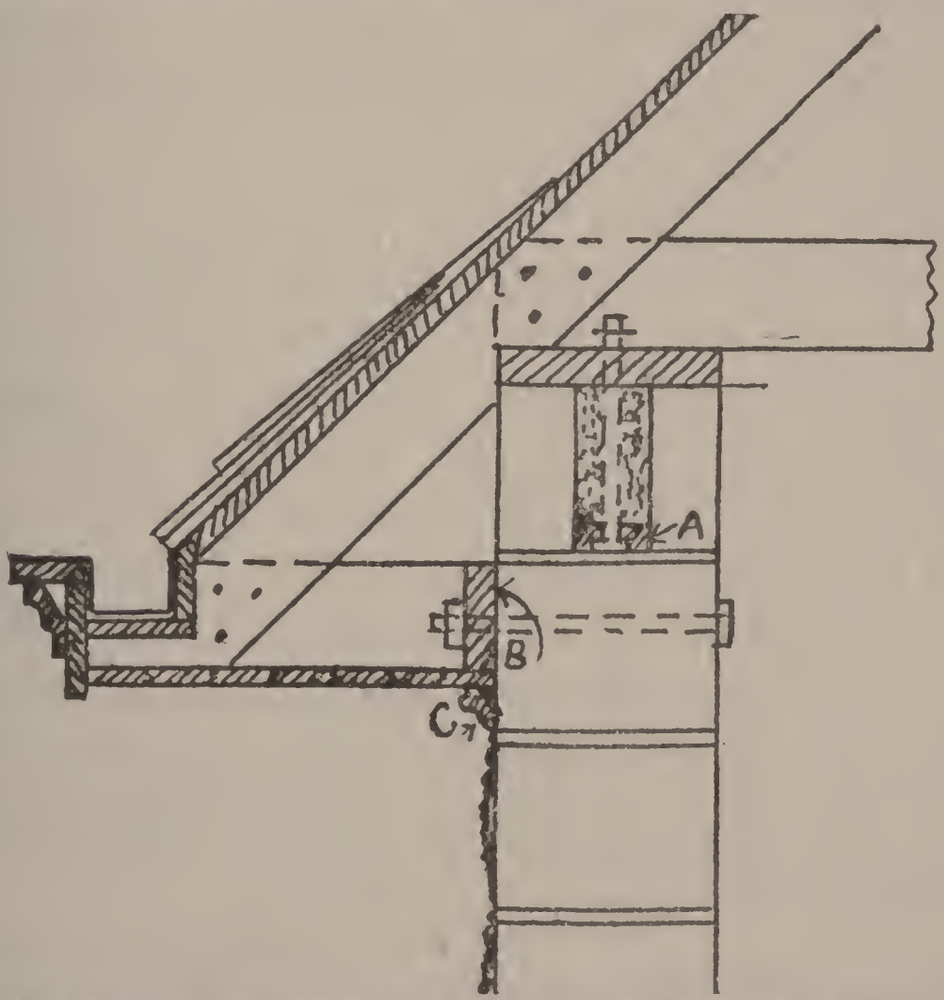


Fig. 56. Method of Fastening Roof Timber Members to Concrete Block Wall.

in solid concrete in the block spaces, as shown in Fig. 56.

The roof, floors, and partitions may be made

as in the ordinary frame house. If fireproof construction is desired, the floors may be made of cast slabs; the partitions of a light grade of blocks; and the roof cast as a slab, or built of framework and covered with concrete shingles.

Plastering Walls. Interior plaster may be placed directly on the inner surface in the case of a wall with air-space, or the wall may be furred and lathed as in ordinary construction. Often furring is omitted in hollow walls, and a moisture-proof, tacky material is smeared onto the inside surface to act a binder in holding the plaster in place.

Exterior Finish. Much has been said about the monotonous appearance of concrete block houses. Probably this is due to the prevalence of the rock-face type of finish, which is used to so great an extent and too often without realizing the possibilities of variation in effect. This type of surface is often criticised on account of the attempt to imitate another material. While there may be parts of a building, such as foundation walls, where this imitation stone may be used with apparent fitness, it should not be used indiscriminately.

Concrete is just as good a building material as ever was used, and does not need an excuse for being present in a structure; nor can the finest results be secured where it is obviously disguised as if to avoid detection. By the use of properly selected aggregates or facing mixtures, concrete blocks may be made to show an

individuality which will stand on its own merits. Beautiful designs can also be worked out by the use of blocks of different sizes and contours, giving the effect of broken ashlar, etc. The proper treatment of exterior surfaces, in fact, will bring out artistic effects which cannot be produced in any other building material.

Framing for Block Construction

The extensive use now made of the cement block as a building material has naturally raised the question of proper and economical door and window frames, and the method of constructing them and placing them in the walls. Thousands of men are engaged in making commercial blocks in a small way, but the great majority of them are all at sea when a prospective builder asks for information as to how the frames for one of these block buildings should be made. If the customer is within reach of a mill-work concern, he can have his particular needs figured out and supplied from that source; but in many cases the local carpenter has to design the frames, and has not that large experience of the mill man to guide him to both efficiency and economy, and so is apt to make bunglesome and expensive frames.

There are several distinct classes of frames used in buildings made of cement blocks; and it is the purpose of this article, with the accompanying drawings, to cover this ground with practical information which will enable the

builder to suit his needs by varying some of the dimensions to suit his special size of blocks.

In all of the drawings here submitted, the blocks are assumed to be 10 inches thick and made to lay 8 inches high, while all of the different members of the frame are proportioned to this size, so that if the reader keeps this in mind, he will be looking at a small picture of the real frame and wall in their relative sizes. It must be kept in mind that all of the sizes given are not arbitrary, but many of them may be varied to suit different blocks, or to conserve the use of such material as the builder may have to use in the construction of the frames. These points will generally be noted when taking up the discussion of the different styles of frames.

Box Frame for Furred Walls with Rabbeted Jamb-Blocks. Fig. 57 (1) shows a block wall with 1-inch furring and lath and plaster on the inside, making a total thickness of 11¾ inches. The rabbet in the block leaves an offset of 2½ inches each way, and the reveal outside of the hanging stile is 2 inches, as shown at **a a**. This leaves a space for mortar on two sides of the box, and is a feature calculated to make an excellent weather stop.

Instead of bringing the whole weight-box in to the plaster line, the width of the pulley-stile, **b**, is gauged so that an ordinary window stop 1⅜ inches wide will cover the joint between the box and the sub-jamb, **c**. This is particularly for frames having a hardwood finish on

the inside, where the common lumber of the box must be covered from the sash out to the casing with the finishing wood.

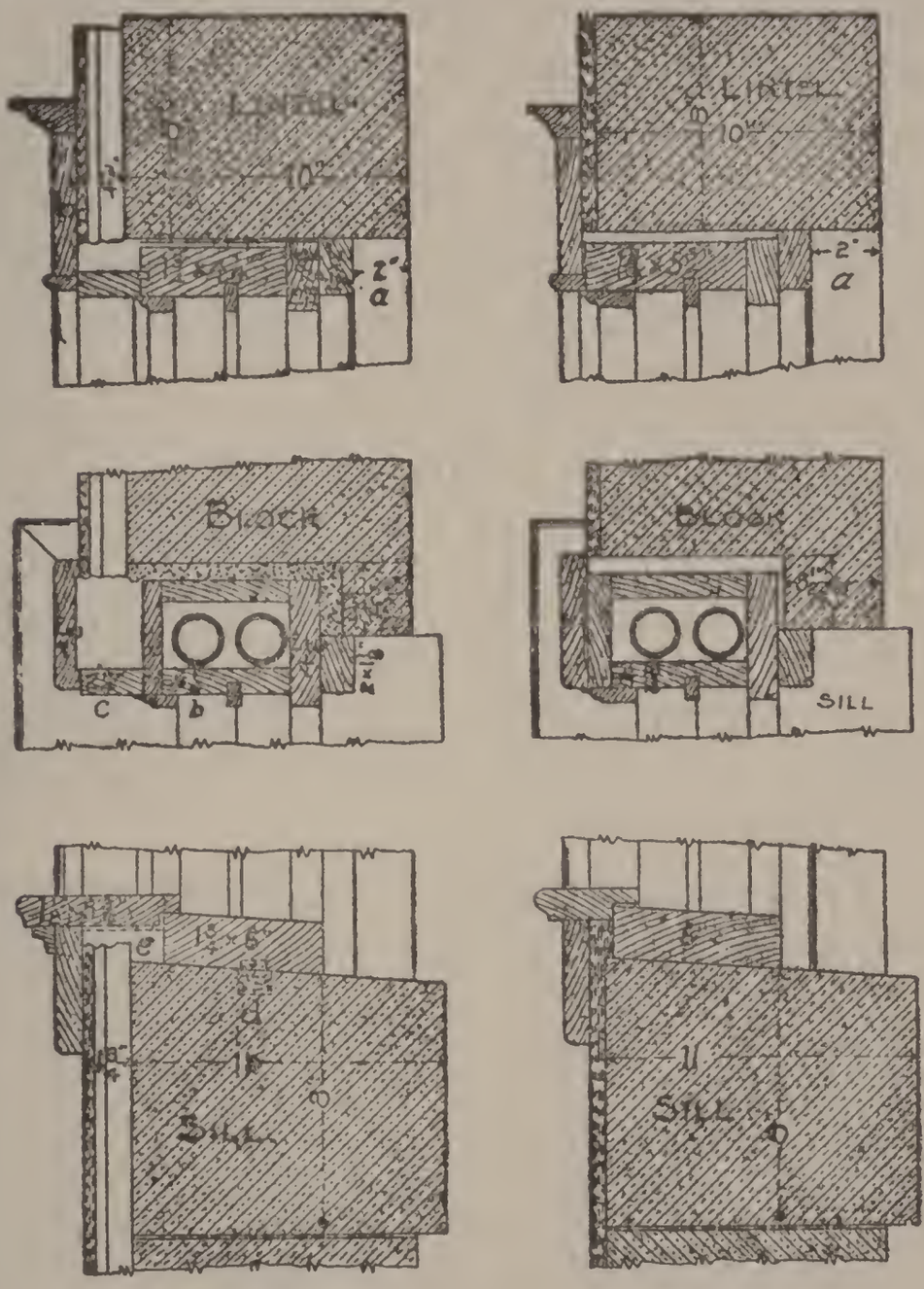


FIG. 1.

Box Frame for Furred Walls.

FIG. 2.

Simple Frame for Unfurred Walls.

Fig. 57. Frames to Use with Rabbeted Jamb-Blocks.

The narrow sill is used in all of the frames shown here; and for use in buildings where the stone sill is made the full thickness of the wall,

they are just as good and much cheaper in material and labor than the ones which extend from the inside of the box out beyond the brick mold or hanging stile. If the block is made with a groove, as shown at **d**, the sill may also be grooved, and filled with a weather strip or with mortar. However, a good practice is to leave the sills both plain, and, then plastering the inside, fill in as shown at the dotted line **e**.

These frames are drawn for windows 1¾ inches thick; and if windows 1⅛ inches thick are used, the box will have to be reduced in width and the sub-jamb widened, or else the window stop will have to be made wide enough to cover the point, as shown in the figure. If the windows are very large, the box may be widened a half-inch in the wall. to accommodate the heavier weights.

Box Frame for Unfurred Walls with Rabbeted Jamb-Blocks. Fig. 57 (2) shows a simple box frame, made thick enough to fill the wall by giving a 2½-inch reveal on the outside and having only the ½ inch for plaster on the inside. The rabbet in this block is 1 inch less than in Fig. 57 (1), so that the frame sits closer to the block and at the same time shows a wider reveal to the molding at **a**. It will be noticed that the side members of this frame are wider than the first, but the front and back are the same. In all of the box frames, the sills are made of a width to permit the inside casing of the box to extend down on the inside and to

nail without making a cut in the sill, while the same is true of the molding on the outside. This allows for making the gains across the sills with-

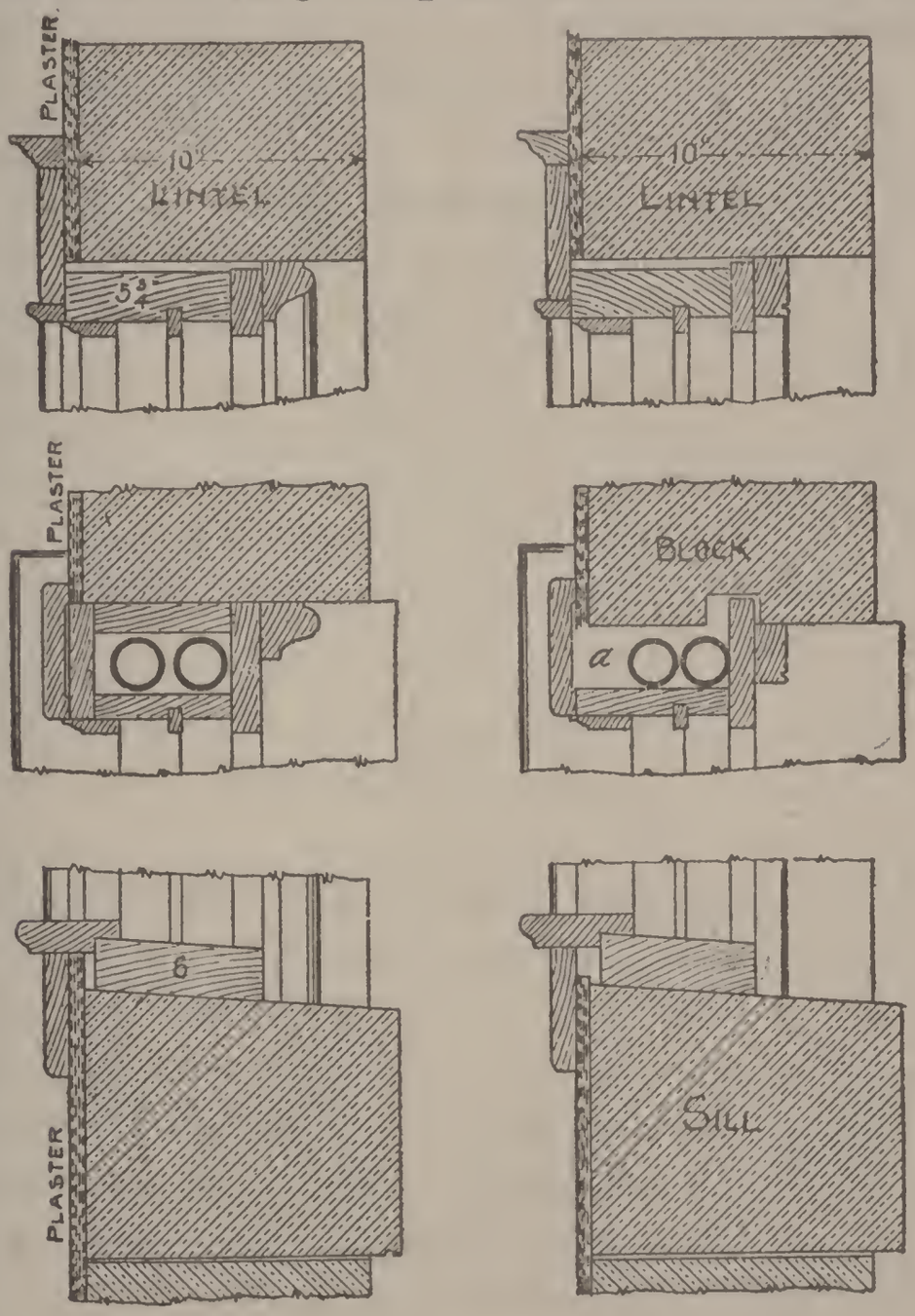


FIG. 3.
Box Frame for Plain Block Wall.

FIG. 4.
Grooved Blocks Form Back of Weight Box.

Fig. 58. Details of Framing for Block Walls.

out any hand work if the frames are made in a mill, and requires the least possible labor if made by hand.

There are certain variations of this frame that may seem desirable if it is to be painted, such as rebating the inside casing and using a narrower window-stop. If the finish is oil or hardwood, then the drawing indicates the cheaper way.

Box Frame in Plain Block Wall. Fig. 58 (3) shows a box frame set in a plain block wall, having neither groove nor rabbet; and the width, or rather thickness, of the frame is determined by the amount of reveal desired on the outside. In this case a heavy molding is shown, and the same may be used on any frame for blocks; but of course it will vary the thickness of the frame or the width of the reveal. It is well to keep in mind a convenient place to hang screens, storm sash, or shutters, and the flat brick molding provides such a place.

Grooved Blocks Form Back of Weight Box. Fig. 58 (4) shows a frame that has become quite popular in some sections of the country, and it is both economical and efficient. In this case the block wall itself forms one side of the weight box, and the blind stop extends into the groove in the blocks, making an excellent weather stop. A thick head is shown in this frame, but this really is not necessary unless the frames are exceptionally wide. The sill is made narrow enough to get out of a 2 by 6, and does not reach to the inside of the pulley stile; but this is one of the economies in frame making and is worth while to remember.

Some builders prefer the outside molding made wider, so as to come on line with the inside opening of the frame; and this is not a bad idea, as it leaves the width of the screen opening the same as that of the window.

Cheap Frame for Double-Hung Windows. Fig. 59 (5) shows the simplest and cheapest style of window-frame for block walls. This frame does not provide for weights, and the simple quarter-round molding is used for outside molding and for inside window-stops. This is a suitable frame for double-sash or check-rail windows in warehouses, dungeons, garages, and such like structures. If the walls are thick and there is no inside casing, the window jambs need be only just wide enough to receive the window-stops on the inside of the sash.

Frame No. 5 may be made into a plain rail window-frame by leaving out the parting stop and putting a flat stop under the upper sash; this will take up ½ inch less room in the thickness of the frame.

Plank Frame for Pivoted Sash. Fig 59 (6) illustrates a plank sash frame for a pivoted sash; and it is very cheaply made out of 2 by 6 material, by rabbeting each side so that a ½-inch strip is left in the middle as wide as the sash is thick. The sash is hung in this space and stopped with quarter-round, which laps over against the rabbet. The molding is fastened to the sash on the upper half of the inside and the lower half of the outside, so that when

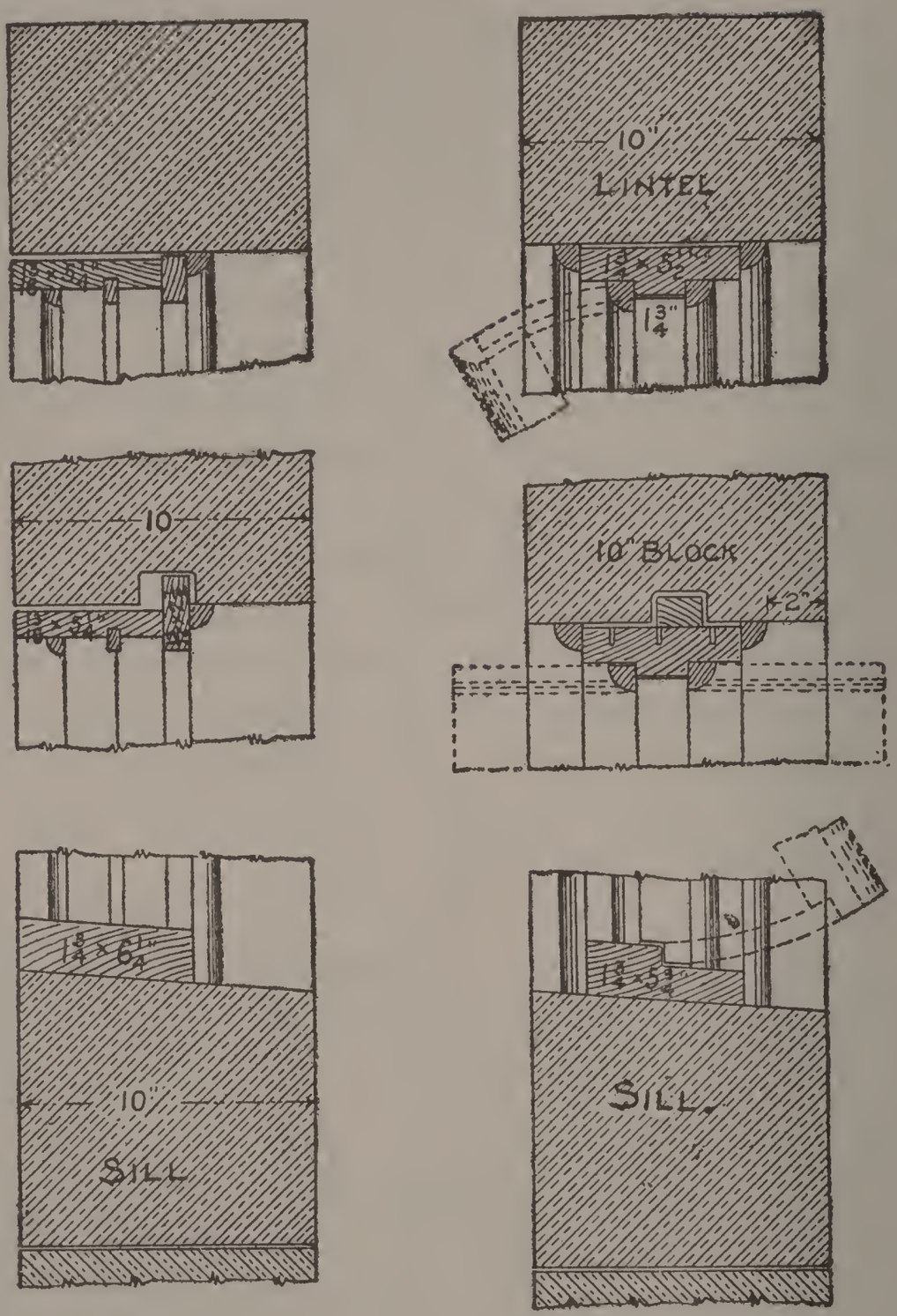


FIG. 5.
Cheap Frame for Double-Hung Window.

FIG. 6.
Plank Frame for Pivoted Sash.

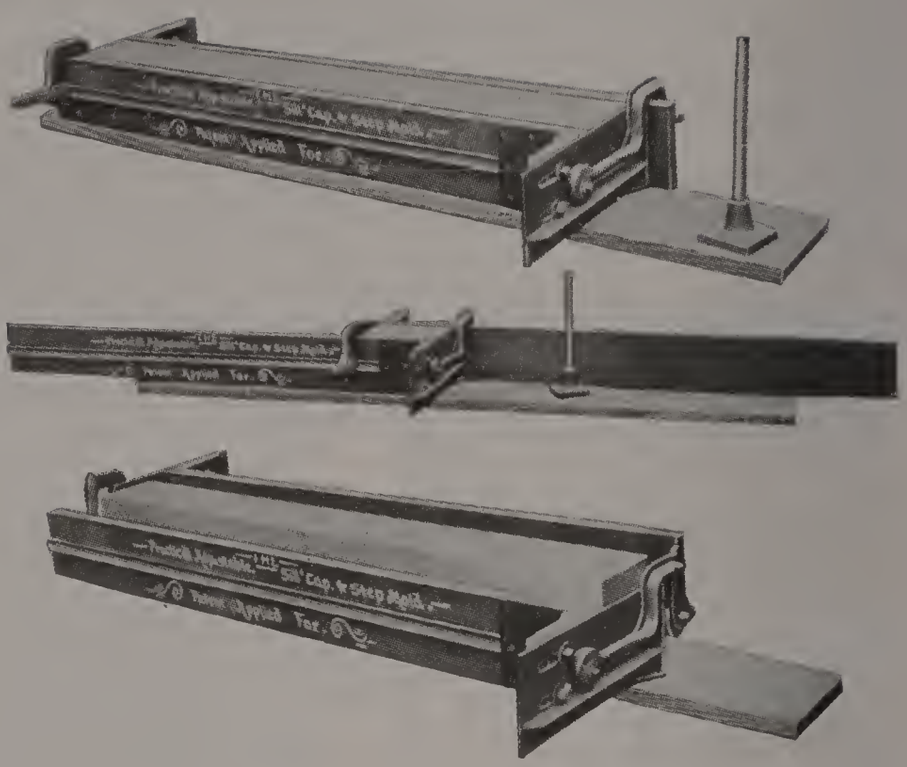
Fig. 59. Details of Framing for Block Walls.

the sash is closed there is a double stop. The sill and the sash are both rabbeted, and this makes a very snug frame when finished. This

CEMENT ROOFING MACHINE.

CONCRETE MIXER.
Showing mixer tilted for discharge.

REINFORCED CONCRETE ROOFING SLATE AND FLOOR-TILE MACHINE.



CONCRETE SILL, STEP, AND CAP MOULD.

VENTILATED CONCRETE FLUE MACHINE.

HAND-POWER CONCRETE MIXER.

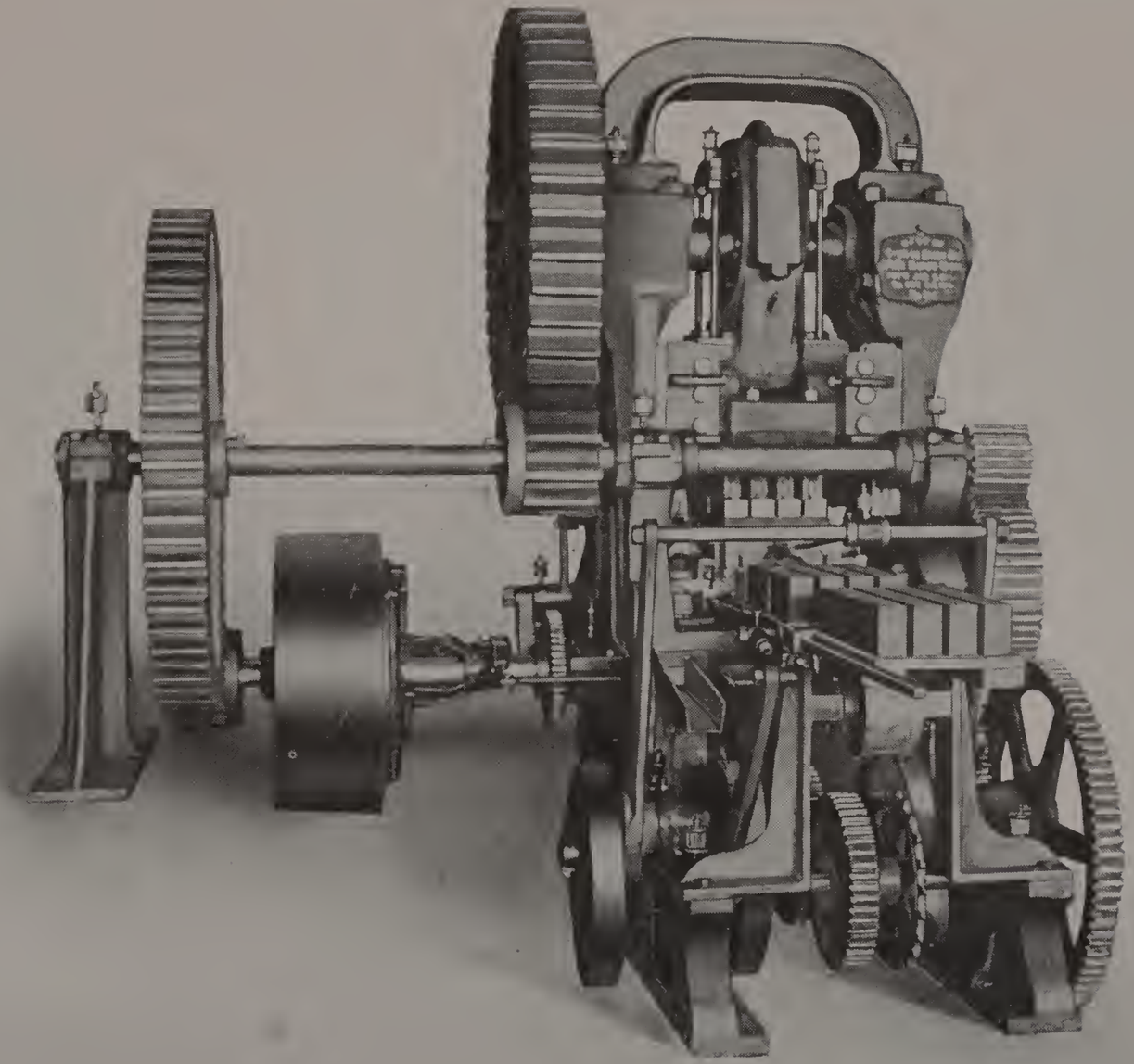
CEMENT BLOCK MACHINE.

FACE-DOWN CONCRETE BLOCK MACHINE.

CEMENT BRICK MACHINE.

CEMENT BRICK MACHINE.

CEMENT BRICK MACHINE.



END VIEW OF AUTOMATIC SAND-CEMENT BRICK MACHINE.

Showing pressed brick coming from machine on the pallets on which they are made, and on which they remain until cured.

style of jamb may be finished on the outside with the regular molding, and on the inside with

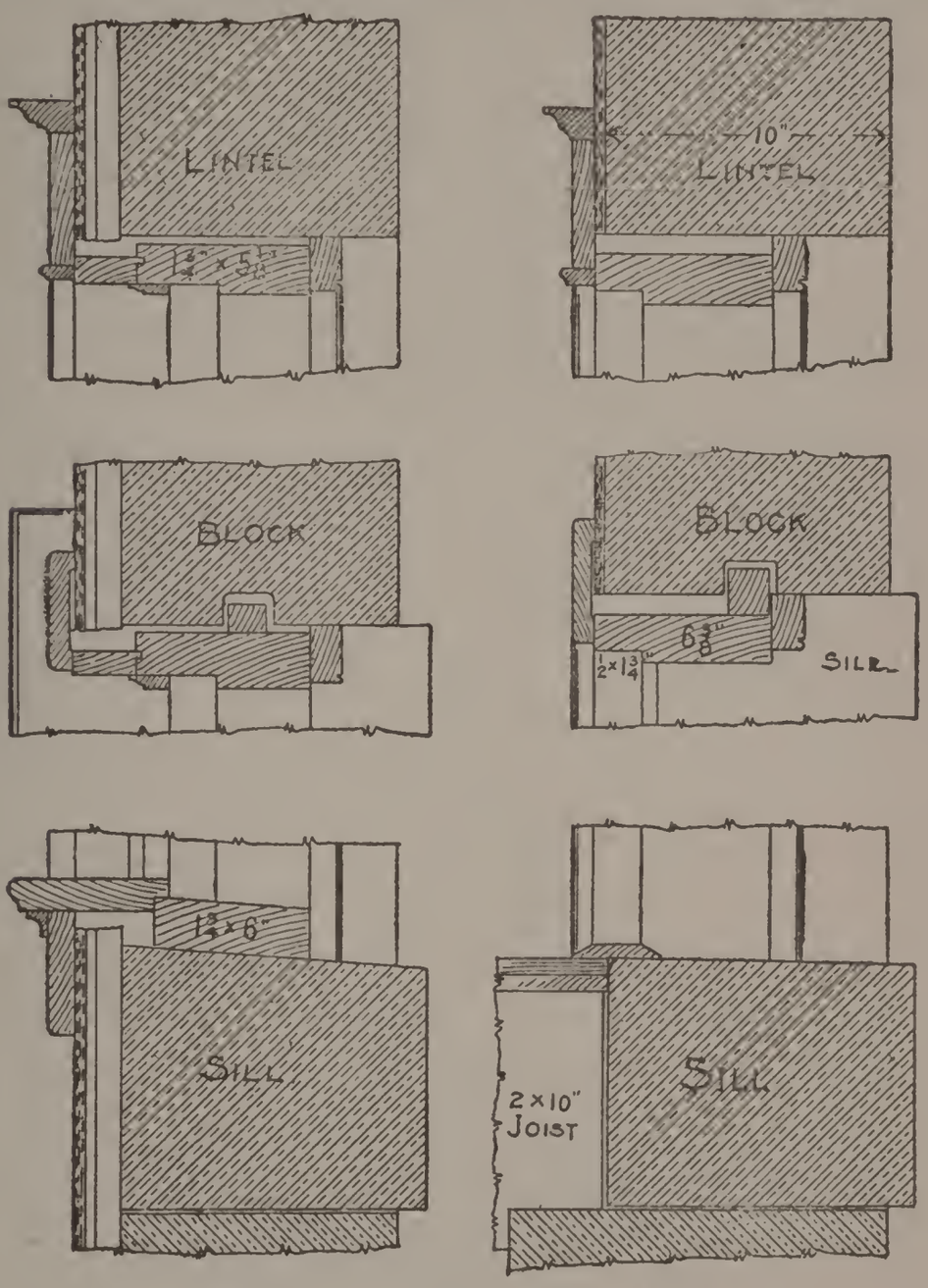


FIG. 7.
Best Style Sash Frame.

FIG. 8.
Plank Rabbeted Door Frame.

Fig. 60. Details of Framing for Block Walls.

the hardwood trim, if it is desired to have a pivoted sash in the better class of buildings. This style of frame is often used for openings

high up out of the way, where it is easier to open and shut with a cord than by other means.

Best Sash Frame. In Fig. 60 (7) we find a sash frame to correspond with the box frame shown in Fig. 57 (1). If we were building a bank building, city hall, or schoolhouse having check-rail windows, plate glass sash, and a good front entrance, we should use the details shown in Figs. 57 (1), 60 (7), and 61 (9 and 10).

The sash frame in Fig. 60 (7) is laid out to take the same width of sub-jamb and stops as the corresponding box frame; and it is quite a help in getting out the trim for a building to have all of the stuff for the windows and sash of the same width. If the frame was varied in thickness for the box frame, then the same change should be carried through the sash frame. It will be noticed that the position of the sash in the jamb is regulated by the width of stop used to cover over onto the sub-jamb, so that, if the sash is thinner, the rabbet will have to be narrower or else a wider stop will have to be provided.

Fig. 60 (8) shows a common plank rabbeted door-frame, which does not differ from that for a brick wall except for the weather strip on the back of the jamb, and even that is often specified for frames in brick walls. There is no wooden sill shown for these frames, for it is taken for granted that a man who makes cement blocks will also make his sills and lintels of the same materials.

The width of the jamb is determined by the finished thickness of the wall, and the desired reveal outside of the brick mold. The weather strip can be nailed on the back of the jamb at any point to fit the groove in the stone.

Mullion Transom Front Entrance Frame. Fig. 61 (9) shows a vertical section through a mullion transom front entrance frame, detailing the head and transom bar. The jambs are rabbeted for the door, and the same for the transom over the door. The dotted line shows the rabbet for the side lights, which are made deep enough to allow for the 1⅜-inch stop to cover from the inside of side light to the inside casing, which is better shown in the cross-section of Fig. 61 (10).

Some architects have designed side lights and transoms to stand flush with the edge of the jambs the same as the doors; but they do not look right, and the practice of setting them in the middle of the jambs and stopping both sides is all right unless the door part of the frame has rabbeted jambs. In this latter case, the door and side light trim will not line up by ½ inch, and that will not look right, either. So, we either rabbet the whole frame or leave it all plain for stops. Like the other door-frame shown, this entrance frame may have jambs of any suitable width; and where the mullions are made up strong, like the ones shown, lumber 1½ inches thick is plenty heavy enough for the jambs. If plain jambs and stops are used, then 1¼-inch lumber is thick enough.

If the builder will study this series of details in connection with the block he is producing, and consider the needs of the building to be put

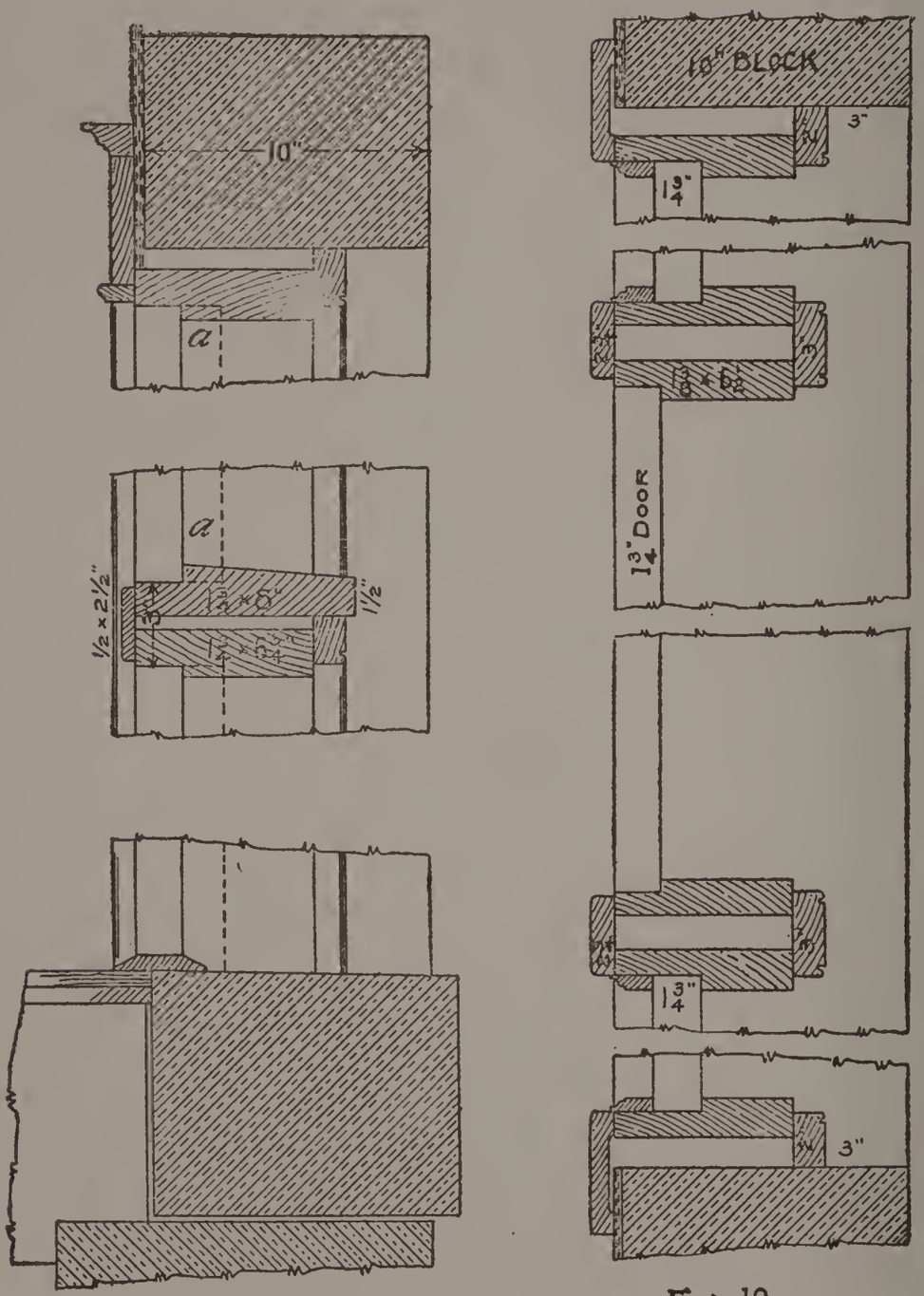


FIG. 9.
Vertical Section.

FIG. 10.
Horizontal Section.

Fig. 61. Mullion Transom Front Entrance Frame.

up, he will be able to adapt the proper one to his use by suiting the dimensions of the different members to sizes of his blocks. He will be able

to figure out his frame and window openings from the glass sizes desired; and his carpenter can make the frames with the assurance that when they are done he will have a job along the lines of the best mill practice, even though he is not within a hundred miles of a house-trim factory.

Number of Blocks Required

In estimating the number of blocks required, the simplest method to pursue is to figure out the superficial or face area of the building. First, multiply the length around the building (in feet) by the height of the wall (also in feet); let us call this quantity **a**. Find the surface of gables by multiplying width of gable by its height, and dividing by 2; call this quantity **b**. Find the surface of each opening by multiplying its width by its height, and add together all the areas of the openings; call this quantity **c**. Then add together the quantities **a** and **b**, and subtract from their sum the quantity **c**. The result will be the net or actual face surface to be covered with the blocks (in square feet). Divide this by 100 by simply pointing off two figures at the right, and this will give the number of squares of 100 feet each to be covered.

Then turn to Table XXV and multiply your number of squares by the number in the right-hand column opposite the size of block to be used. The result will be the number of blocks needed for the building.

For example, suppose the superficial area

TABLE XXV

Concrete Block Table

Size of Block			Solid Blocks			Hollow Blocks			No. of Blocks per Square of 100 Feet
Height	Width	Length	Weight of Block (lbs.)	No. per bbl. Cement at 1:5	No. per Cu Yd.	Weight of Block (lbs.)	No. per bbl. Cement at 1:5	No. per Cu. Yd.	
8	8	16	73	34	48	50	49	71	112
8	10	16	92	27	38	67	37	71	112
8	12	16	109	22	32	80	31	44	112
4	8	16	35	68	99	24	100	144	224
4	10	16	44	54	79	32	70	109	224
4	12	16	53	44	66	39	63	91	224
8	4	16	37	68	95	....	....	....	112
8	8	24	112	22	31	77	32	45	75
8	10	24	140	18	25	92	25	38	75
8	12	24	166	15	21	112	21	31	75
4	8	24	54	46	65	37	66	94	150
4	10	24	67	36	52	46	52	76	150
4	12	24	79	30	41	55	44	63	150
8	4	24	55	44	63	....	....	....	75

The figures given in the above table for the weight of hollow blocks and the number produced from one barrel of cement, can, of course, be taken as only approximate, since the size of the air-space in different blocks varies. It ranges from about 27 to about 32 per cent, or averages about 30 per cent, of the total space occupied by the block.

to be covered is 1,525 square feet. This will be 15.25 squares of 100 feet each. If the blocks are to be 8 by 8 by 16 inches, find this size in the left-hand column of the table, and look across to the right, where you will find the number 112. Then $112 \times 15.25 = 1{,}708$, which is the number of blocks required.

Cost of Concrete Blocks. The following example of cost calculation is based on conditions that may be regarded as approximately standard:

The facing mixture is 1 part Portland cement to 2 parts coarse, sharp, clean sand; and the body of the block 1 part cement to 2 parts sand and 3 parts gravel or broken stone, the gravel or broken stone to range in size from one-fourth to three-fourths of an inch in diameter.

One barrel cement contains 3¾ cubic feet.

One cubic yard contains 7¼ barrels.

One cubic yard of sand and 3⅝ barrels of cement will give a 1:2 mixture of cement and sand.

One cubic yard of sand and gravel and 1½ barrels of cement will give a 1:5 concrete mixture.

For manufacturing 100 blocks 8 by 8 by 16 inches in size, there are needed 2.24 barrels of cement, 0.68 cubic yard of sand, and 1.06 cubic yards of gravel or broken stone. The cost of making 100 blocks will therefore be approximately as follows:

2.24 bbls. best Portland cement @ $2.00 per bbl.	= $4.48
0.68 cu. yd. sand @ $1.00 per cu. yd.	= .68
1.06 cu. yds. gravel or broken stone @ $1.50 per cu. yd.	= 1.59
Cost of labor for 100 blocks	= 1.75
Incidentals for safe margin per 100 blocks	= .50
Total cost of 100 blocks 8x8x16 in.	= $9.00

The above figures are conservative estimates of cost for materials and labor. They may vary to a greater or less degree, depending on the locality—distance from sources of supply, local labor conditions, etc.

Ordinarily blocks cost less than common brick. For comparison of cost with brick construction, the following figures showing the equivalent number of brick displaced by blocks of various sizes, will be found of help:

Size of Block with Mortar Joints	Equivalent No. of Brick Displaced
8x 8x16 in.	14.22
8x10x16 in.	17.77
8x12x16 in.	21.33
4x 8x16 in.	7.11
4x10x16 in.	8.88
4x12x16 in.	10.66
8x 4x16 in.	7.11
8x 8x24 in.	21.33
8x10x24 in.	26.66
8x12x24 in.	32.00
4x 8x24 in.	10.66
4x10x24 in.	13.33
4x12x24 in.	16.00
8x 4x24 in.	10.66

CEMENT BRICK MACHINES

Many of the companies manufacturing concrete block machines have also developed special machines for the making of cement brick. Some of these machines are hand-operated; some power-driven; and of the latter, the higher-class machines are equipped with automatic power tampers.

CEMENT DRAIN-TILE AND SEWER-PIPE MACHINES

Cement tile have abundantly demonstrated their efficiency and durability for drainage purposes. Their permeability is a feature that can be controlled by the manufacturer. Tile can be made porous so as to give effective drainage throughout their length; or they can be made water-tight so as to admit water only at the joints, like ordinary clay tile. If properly made of well-selected material, they grow stronger with age. Concrete sewer pipe laid in the city of Milwaukee, Wis., were found intact after twenty years of service; and similar results have been noted in London, England, where concrete pipe and tile laid underground have been found in perfect condition after forty years of service. In many cities, concrete sewers are replacing brick sewers on account of the more satisfactory wearing qualities of the former. When properly cured, cement tile will withstand alternate freezing and thawing without injury, even when partially immersed in water. In the construction of a county ditch near Emmetsburg, Iowa, nearly a mile of cement tile lay stretched out through a swamp for eighteen months, or through two winters, before placing in the work. Some of these tile were entirely submerged, others partially, and some were entirely out of water. They were subjected to freezing and thawing, and yet remained in perfect condition.

On account of their thin walls, cement pipe and tile are not so easily made as cement blocks. Tile machines, however, are now made with all the skill and ingenuity embodied in block machines, and with perfectly efficient adaptation to their purpose.

Concrete drain-tile and sewer-pipe are no longer an experiment. Even though pages of matter intended to injure have been written by the agents of industries whose products have suffered either from comparison with concrete or from the universal favor with which concrete has been accepted by the public in general, repeated tests and expressions of confidence from persons of authority have shown that concrete is a suitable material to use for water-carrying and drainage purposes. Where failures have occurred, probably a close investigation would show that the fault was with the method of manufacture of the pipe, or with the way in which it was handled after making. The material itself was not at fault.

Burned clay pipes and tile were formerly used for nearly all drainage purposes where there was but little or no pressure to be resisted. Cement pipes are now made and used in the place of burned clay products, with the best of success. Where pressure is to be resisted, or where heavy loads are to be carried on top of the pipe line, as in the case of a large-diameter pipe which is buried to a considerable depth in

soil of an unstable nature, reinforced concrete pipes are used.

In large forms of construction, such as sewers or drains which are to carry large quantities of water, concrete is most adaptable, since it can be placed without the use of heavy machinery and is made at the site of the work. The materials, with the exception of the cement, may be found near the work, thus bringing down the cost of transportation to a minimum. No costly machinery is needed for making the large sections of pipe used, and the concreting plant moves along with the work as it progresses. The collapsible steel forms which are used in the ditch to serve as a mold for the pipe are cheap, easily handled, and may be obtained in all economical sizes.

The smaller or common sizes of pipe and drain-tile are made in separate sections away from the direct site of the work, by the use of either power-driven or hand-operated tile machines or outfits. The main advantages in the use of concrete instead of clay for these smaller-size pipes and tile, may be summed up as follows: Cement tile grows stronger with age, while clay tile are the strongest when they come from the plant. Cement tile are more uniform in size and more regular in shape than clay tile, thus making cement tile easier to lay. The degree of permeability of cement tile is controlled by the manufacturer of the tile, since the richness or wetness of the concrete mixture will

determine the porosity of the tile. Porous tile will give effective drainage throughout their whole length, while a dense tile will allow drainage only at the joints between sections. Clay tile are of the nature of a dense concrete tile in regard to porosity. The fact that cement tile will successfully stand alternate freezing and thawing without injury, allows them to be used in places where clay tile would be completely destroyed by such action. This property of concrete tile also allows winter distribution in locations where it would be impossible to drive a team at other seasons of the year. Also it is claimed that cement tile are cheaper in first cost under ordinary circumstances. Concrete pipes and tile are less brittle than clay tile, therefore are not so easily broken in handling or by having heavy objects dropped on them.

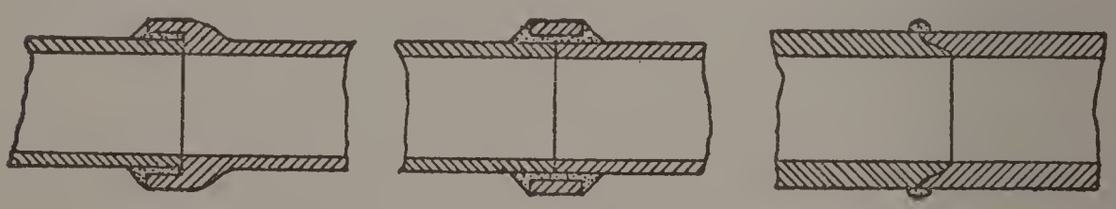


Fig. 62. Types of Tile Ends, and Method of Forming Tight Joints When Desired.

Cement tile are made in almost any shape, size, or thickness desired, from the simple **butt-end type** to the special **egg-shaped section** sometimes used for sewer work. While the common type is round in cross-section, the shape of the ends of the pipe may vary, as shown in Fig. 62. The joints shown in Fig. 62, from left to right, are called the **hub-and-spigot joint**, the **ring** or

butt joint, and the **bevel joint**. **Bell-end joints** are a form of the hub-and-spigot joint; and pipes with these joints may be made either "bell up" or "bell down." The degree of tightness of these joints when laid will depend upon the care in placing and filling, since cement tile are even in contour and no large or uneven cracks need occur, such as are due to the warping of clay tile. This absence of irregularity due to warping, also allows the use of the bevel joint with concrete, where a hub-and-spigot joint would be necessary with clay tile.

Cement tile may be made by anyone in nearly any place, and with or without special machinery—from the young man on the farm, with a simple, hand-operated outfit, up to the manufacturer who has an established plant similar to that shown in Fig. 63. As with other phases of the use of cement, no large amount of capital is necessarily needed. The boy on the farm and the big manufacturer each make a good cement tile, the difference lying in the economy of operation and the output of the plant.

Since the demand for tile machinery has become so great, the manufacturers of concreting machinery have placed various types of tile machines on the market, designed to take care of all sizes and classes of work. Small **hand outfits** may now be obtained at a low cost; and more complicated **power-driven machines** suited to the needs of the largest manufacturer are in constant demand.

Details of Manufacture. The detailed mode of procedure followed in making a cement tile with a hand machine, varies with each machine, as in the case of the power machines, but the general principle is as follows: A light, but

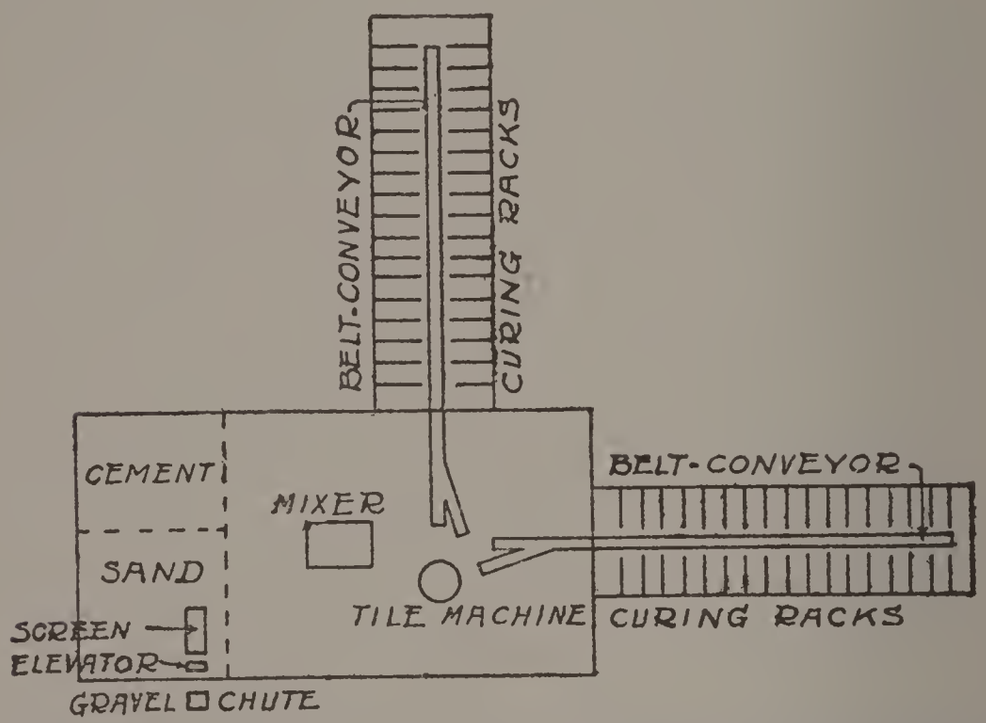


Fig. 63. Typical Layout of a Tile Manufacturing Plant.

rigid core is placed on a pallet or holder of some type, and held firmly in place. These cores may be collapsible or otherwise. A rigid outer shell, which may be opened, is placed around this inner core or form; and the space between the two cylindrical surfaces is filled with concrete. The concrete is shoveled in three or four shovelfuls at a time, and thoroughly tamped with tampers which fit the shape of the mold. Special-shaped end attachments are furnished for bell-end or hub-end pipes. The finished tile is then taken to racks in a drying or curing room

or shed, and the forms are carefully removed to be used again.

These hand outfits are placed on the market at such a low price that it is a waste of time to attempt to make a hand-made outfit, especially where any number of tile are to be used.

For the manufacturer who is to make tile in large numbers, the power machine will give the best results. The general principle of these machines consists of a revolving packer-head, and a platform which moves under or away from the packer-head at each operation of the machine. The details of different makes of machines will vary. In general, a casing which may be opened is placed on the platform, and the packer-head is allowed to pass through this casing. This may be accomplished either by lowering and raising the revolving head, when the platform remains at constant level, or by moving the platform up and down, the revolving head in this case remaining at the same height at all times. Only an amount of concrete sufficient to make a tile of the size desired is admitted to the machine at each operation. This concrete is pressed and packed firmly into the casing, by the revolving head; and then the casing is removed from the machine. After the casing has been removed from the formed tile, the tile goes to the curing room or shed, and the casing is taken back to the machine to be used again.

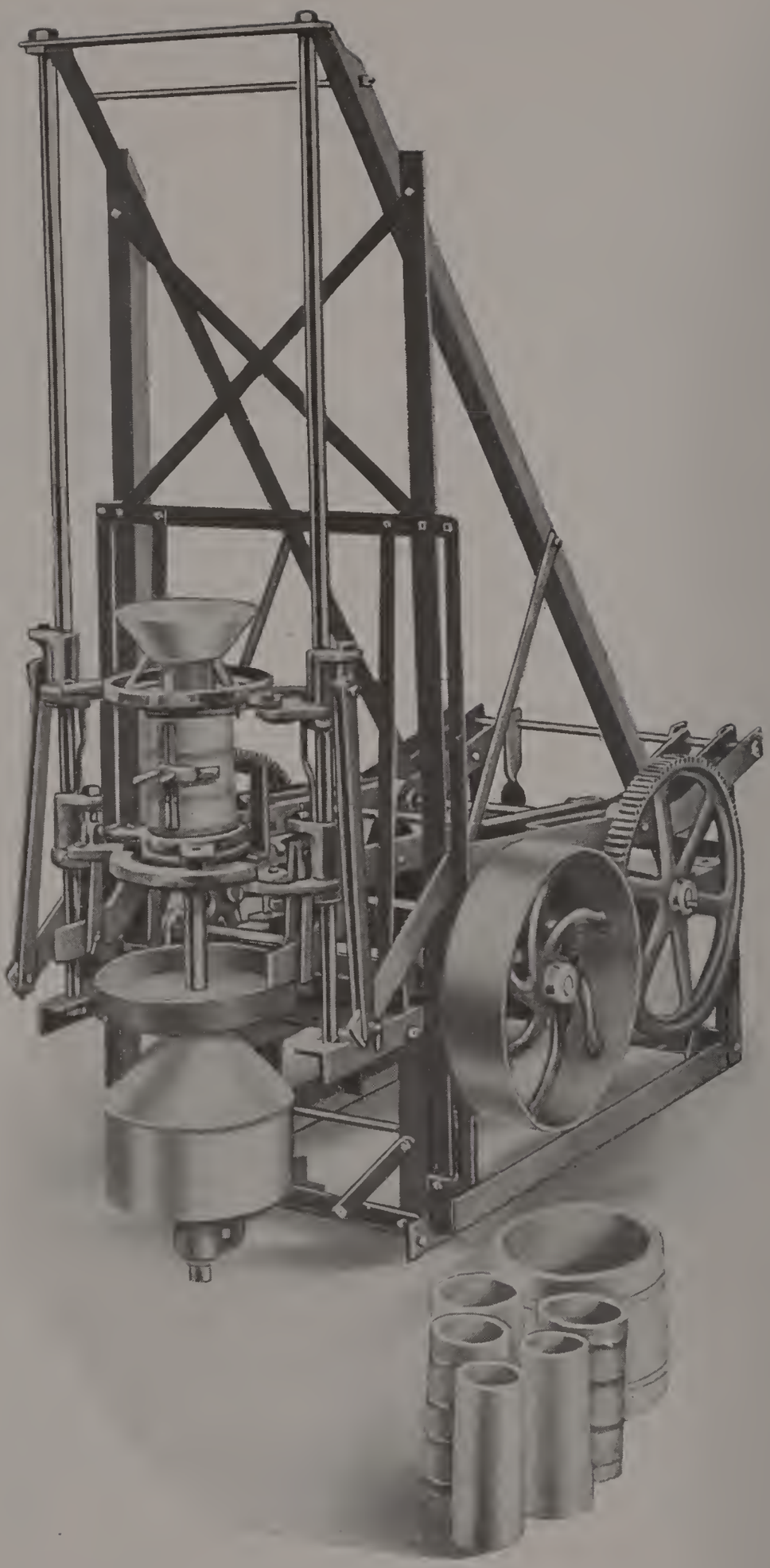
The materials commonly used consist of a

good grade of Portland cement, fresh and free from lumps; and a clean, coarse grade of sand, free from dirt, loam, clay, and all vegetable matter. All particles should pass through a ¼-inch mesh screen; but, if too coarse, a mixture of fine and coarse sand may be made, especially where a dense tile or pipe is desired. Finely crushed stone may be used to take the place of the sand, or to be mixed with the sand. In large work, regular mixtures of concrete may be used where the thickness will permit.

Materials may be mixed by hand or by machine mixer. Machine-mixed concrete is always preferable to hand-mixed; but the amount of material used will not always justify the purchase of a mixer for a given job.

After the tile or pipes are made, they are removed from the machine as stated, and carried to the curing plant or room. The green tile must be handled carefully, to prevent breakage. There are three general methods of carrying these tile away from the machine—by hand, by cars, and by automatic conveyors. The car system is probably the most used at the present time. The most economical method seems to be to allow the tile or pipes to remain on the cars until they are properly cured. The cars are loaded at the machine and run directly into the curing shed. The tile are allowed to remain there until properly cured, and then they are run into the storage yard on the same car. While this system of handling requires a con-

LARGE CEMENT TILE MACHINE.
Will make two sizes of tile at same time.

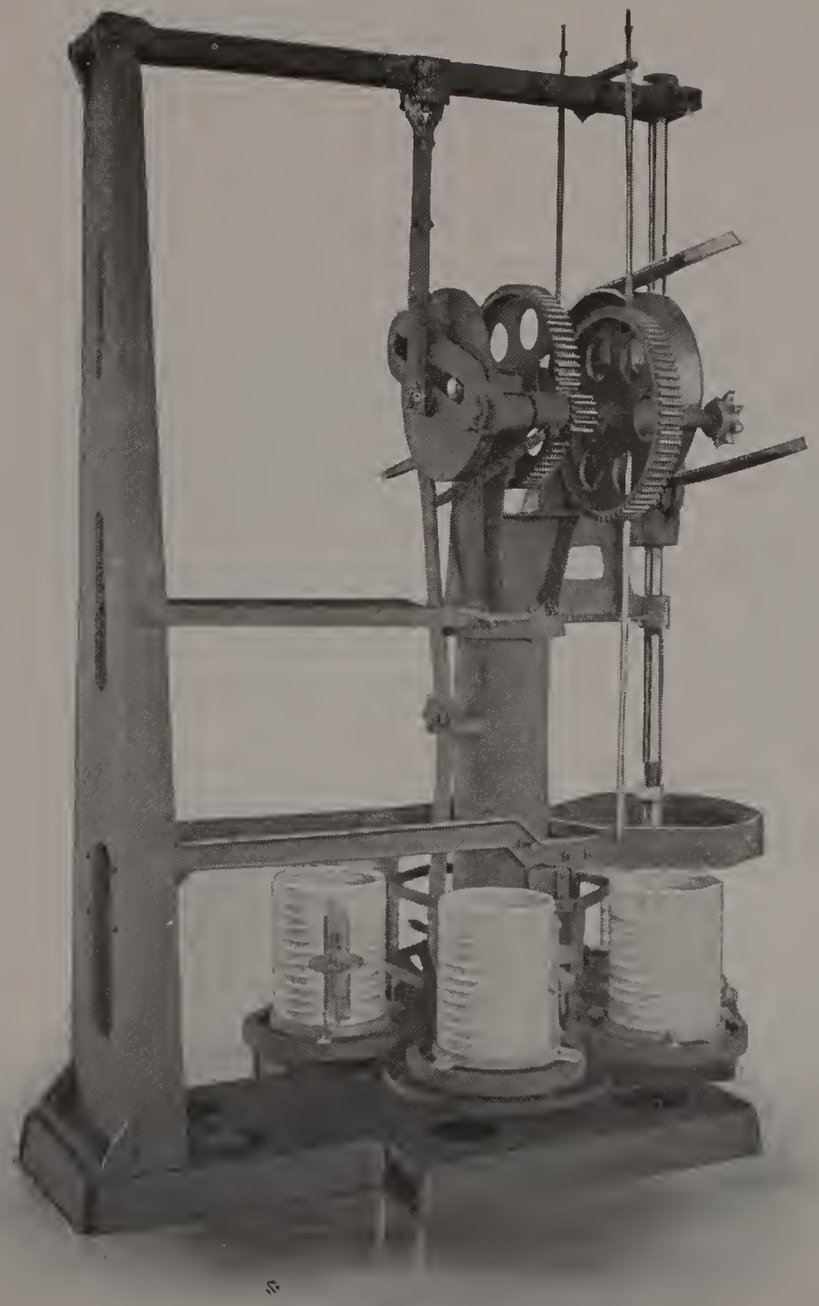


LARGE POWER CEMENT DRAIN-TILE MACHINE.

SMALL BRICK MACHINE.

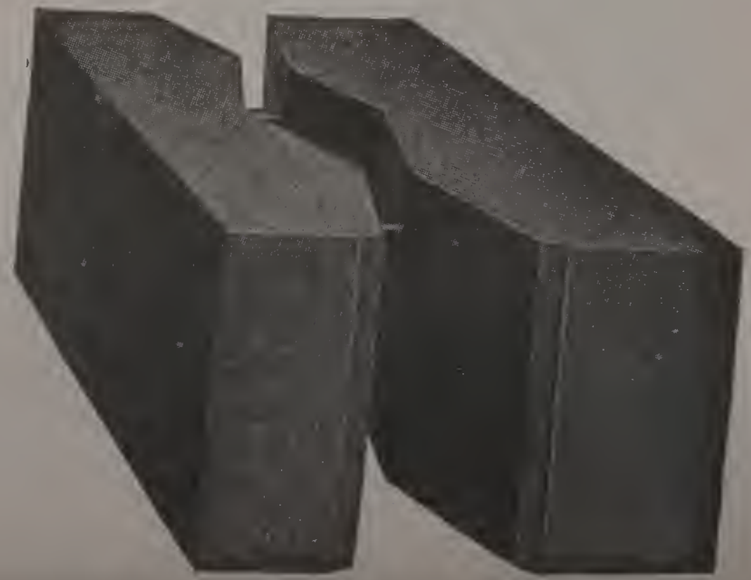
FACE-DOWN BRICK MACHINE.

Bricks are molded face down, but turned face up for removal.



CEMENT DRAIN-TILE MACHINE.

HAND-OPERATED CEMENT TILE MACHINE.
Outfit here shown is for making tiles with bell-end joints.



BLOCK WITH CONTINUOUS AIR SPACE.

siderable outlay for equipment, the saving in labor and danger of breakage is an important factor. Such a system could be employed to advantage only in a very large plant.

The conveyor system may consist of an endless belt running in a trough or through guides, and extending from the machine to the curing plant. The filled casings are taken from the machine, placed on the moving belt, and removed at the curing plant. The stripped casing is then returned by the belt to the starting point.

Curing. The operation of curing or hardening the tile may be accomplished by **sprinkling** with water, or by sprinkling and **steam-curing.** In either case, the tile or pipes are placed on cars or racks in a shed free from drafts of air, or closed tightly when steam is used. Where water is used alone, overhead pipes are installed with sprinklers so arranged as to cover the entire rack area. These sprinklers should be controlled by valves on each line. In small plants, a few pieces of garden hose fitted with revolving lawn sprinklers may be connected to sill-cocks at different parts of the shed and turned on as desired.

Steam-curing plants should be installed in fairly tight sheds. The steam should be brought into the building under the floor, and should not exceed 5 pounds gauge pressure. The combined heat and moisture from the steam hasten the setting of the cement. A steam-curing room may, if necessary, be operated without a boiler.

Place thin plates of sheet iron over gas jets or gasoline torches, and let water drip onto them from above. The water is turned into steam as soon as it touches the hot iron, and the resulting heat and moisture do the curing. If steam from a steam main does not contain sufficient dampness, small quantities of water may be allowed to enter the steam pipes from a special water pipe, thus supplying the necessary moisture. A simple and effective method of increasing the amount of moisture in steam is to allow the end of the steam pipe to stick into the neck of a 2-gallon jug which is about half-full of water. The pipe end should project just below the surface of the water.

In either method of curing, the tile should be several hours old before sprinkling or exposing to steam. When water curing is used, the tile should be sprinkled every six or eight hours for the first week. Then they may be allowed to stand in the shed for two days before removing to the drying yards where they complete the process of curing, which in no case should be for less than 30 days. In hot weather, it may be necessary to sprinkle the tile occasionally while in the yard.

When steam curing is used, steam is not turned onto the product until it is 12 hours old; and the tile are left in the curing room from 18 to 24 hours after the steam is applied. Tile should in any case be protected from sun and wind while curing.

The quality of concrete used in pipes and tile depend upon the use to be made of the tile or pipe in question, upon the soil in which it is to be placed, and upon the nature of the drainage or material which is to pass through the pipe. If a porous tile for land drainage purposes is desired, a mixture of 1 part Portland cement to 4 to 7 parts sand and gravel may be used. It is claimed that a 1:5 mixture gives the best results as to strength and porosity for tile under 8 inches in diameter, while a 1:4 or 1:3 mixture should be used in the larger sizes. This richer proportion is necessary on account of the greater size and weight, thereby causing greater stresses to occur in the material. The gravel in these mixtures should not be greater than ½-inch in size. It is often specified that none of the coarse aggregate shall be larger in dimension than one-half the thickness of the pipe walls. The sand should be clean and coarse, being well-graded from coarser to finer where a dense mixture of concrete is desired for a tight pipe.

The mixtures stated above will make a concrete which will allow more or less drainage along the entire length of a pipe line, as well as at the joints. The degree of porosity of a piece of cement pipe may be determined by holding up a tile in one hand and pouring water in a small stream on the outside surface. In the case of a porous tile, the water will not run off along the sides, but will pass through and trickle down to the floor of the tile and run out.

If a pipe line is desired to carry drainage or water from one locality to another without leakage on the way, or if a stronger quality of tile is desired, a richer mixture or a carefully graded aggregate should be used. A 1 part Portland cement to 2 parts sand or a 1:3 mixture, will produce a dense concrete for this purpose. In large work where the concrete is cast in place, as in the case of sewers or large-size pipe lines, a mixture of 1 part Portland cement, 2 parts clean, well-graded sand, and 4 parts crushed stone is often used. The larger the stone employed, the denser the resulting concrete; but the size may be limited by the rule of not allowing aggregates to be larger in dimension than one-half the thickness of the pipe, by a limiting maximum size of 2½ inches, or by the use of reinforcement. Where reinforcement is used, it is common to specify that 1 inch shall be the largest dimension of this stone. A wash of neat cement is often applied to the inside of the pipe to aid in waterproofing.

Other mixtures will give varying densities to the concrete. Porous tile are subject to the injurious chemical action of acids and other impurities found in drainage, and should be used with caution. The 1:3 mixture is claimed to be free from attacks from ordinary impurities, especially when the tile have been mixed fairly wet and thoroughly cured before laying.

Ordinarily only sufficient water is used to hold the concrete together when squeezed into a

ball, but many recommend a fairly wet mixture. The advantage of a dry mixture is that the castings may be removed at once. If a wet mixture is used in machine-made tile where the tile is formed by a revolving packer-head, there is danger of a movement of the concrete as the head passes over it, and of the formation of ridges on the inside surface of the tile. The concrete should be just wet enough so that if a handful is squeezed up in the hand it will not crumble when released, nor will it stick to the fingers, but will show the imprints of same clearly.

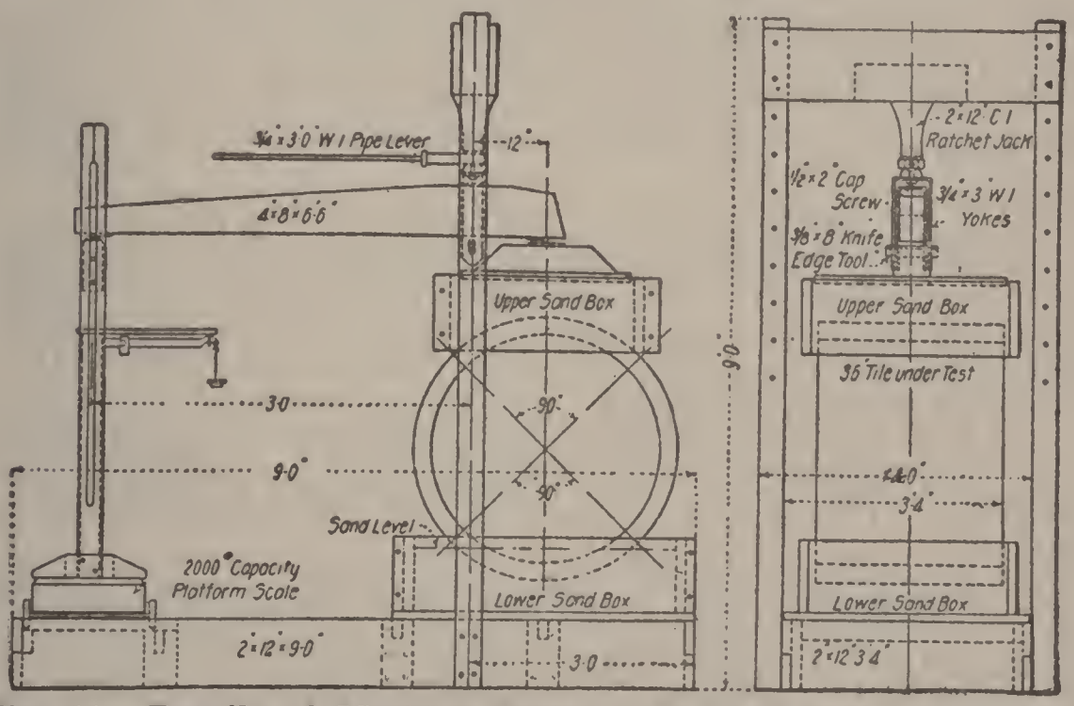


Fig. 64. Details of Machine Designed at Iowa State College for Testing Drain-Tile and Sewer-Pipe.

Tile Testing. The strength and degree of porosity of drain-tile or sewer-pipe may be examined by the standard specifications given below, which are recommended by the Engineering Experiment Station of the Iowa State College. Fig. 64 shows a testing machine which

may be built for fifty or sixty dollars. The power in this machine is applied through the lever attached to the ratchet jack-screw shown in the right-hand diagram. The load is computed from the weight read on the scale beam, and the ratio of the lever lengths. This machine originated at the Iowa State College.

STANDARD SPECIFICATIONS FOR TESTS OF DRAIN-TILE AND SEWER-PIPE

Absorption

1. **Specimens.** The specimens shall be each approximately 3 inches square, and shall extend the full thickness of the pipe wall, with the outer skins unbroken.

2. **Number of Test Specimens.** Five individual tests shall constitute a standard test, the average of five, and the result for each specimen, being given in the report of the test.

3. **Drying Specimens.** Each specimen shall be dried in an oven or by other application of artificial heat, until it ceases to lose further appreciable amounts of moisture when repeatedly weighed.

4. **Brushing Specimens.** All surfaces of the specimens shall be brushed with a stiff brush before weighing the first time.

5. **Weighing.** The specimens shall be weighed immediately before immersion, on a balance or scales capable of accurately indicating the weight within one-tenth of one per cent.

6. **Water for Standard Test.** The water employed in the standard absorption test shall be pure soft water, at the air temperature of a room which is artificially heated in cold seasons of the year.

7. **Immersion of Specimens.** The specimens shall be completely immersed in water for a period of 24 hours.

8. **Re-weighing.** Immediately upon being removed from the water, the specimens shall be dried by pressing

against them a soft cloth or a piece of blotting paper. There shall be no rubbing or brushing of the specimen. The re-weighing shall be done with a balance or scales capable of accurately indicating the weight within one-tenth of one per cent.

9. **Calculation of Result.** The result of each absorption test shall be calculated by taking the difference between the initial dry weight and the final weight, and dividing the remainder by the initial dry weight.

Bearing Strength

1. **Specimens.** The specimens shall be unbroken full-sized samples of the pipe to be tested. They shall be carefully selected so as to represent fairly the quality of the pipe.

2. **Number of Specimens.** Five individual tests shall constitute a standard test, the average of the five, and the result for each specimen, being given in the report of the test.

3. **Drying.** The specimens shall be dried by keeping them in a warm, dry room for a period of at least 2 days prior to the test.

4. **Weighing.** Each dried specimen shall be weighed on a reliable platform scale just prior to the test.

5. **Bedding of Specimen for Test.** Each specimen shall be accurately marked, with pencil or crayon lines, in quarters, prior to the test. Specimens shall be carefully bedded, above and below, in sand, for one-fourth of the circumference of the pipe, measured on the middle line of the tile wall. The depth of bedding above and below the tile at the thinnest point shall be equal to one-fourth the diameter of the pipe, measured between the middle lines of the tile walls.

6. **Top Bearing.** The top bearing frame shall not be allowed to come in contact with the tile or with the test load. The upper surface of the sand in the top bearing shall be carefully struck level with a straight-edge, and shall be carefully covered with a heavy, rigid top bearing,

with lower surface a true plane, made of heavy timbers or other rigid material capable of uniformly distributing the test load without any appreciable bending. The test load shall be applied at the exact center of this top bearing in such a way, either by the use of a spherical bearing or by the use of two rollers or rods at right angles, as to leave the bearing free to move in both directions. In case the test is made without the use of a machine, and by piling on weight, the weight may be piled directly on a platform resting on the top bearing, provided, however, that the weight does not touch the top frame holding the sand, and provided, further, that the weight is piled in such a way as to insure uniform distribution of the load over the top surface of the sand.

7. **Frames for Top and Bottom Bearings.** The frames for the top and bottom bearings shall be composed of timbers so heavy as to avoid any appreciable bending by the side pressure of the sand. The frames shall be dressed on their interior surfaces. No frames shall come in contact with the tile during the test. A strip of soft cloth may be attached to the inside of the upper frame on each side along the lower edge, to prevent the escape of sand between the frames and the tile.

8. **Sand in Bearings.** The sand used for bedding the tile at top and bottom shall be washed sand which has passed a No. 8 screen. It shall be dried by keeping it spread out thin in a warm, dry room.

9. **Application of Load.** The test load shall be applied gradually and without shock or disturbance of the tile. The application of the load shall be carried on continuously, and the tile shall not be allowed to stand any considerable length of time under a load smaller than the breaking load.

10. **Calculation of the Bearing Load.** The total breaking load shall be taken as equal to the total top load, including the weight of top frame, sand for top bearing, top bearing timbers, etc., plus five-eighths of the weight

of the pipe. This total load shall be divided by the length of the pipe in feet, so as to give the bearing strength per linear foot of pipe.

Modulus of Rupture. The modulus of rupture for drain-tile and sewer-pipe shall be computed from the results of the standard test for bearing strength, according to the following rule:

Divide the bearing strength per linear foot by 12; multiply the quotient by the radius of the middle line of the tile wall, expressed in inches; and divide this product by the square of the minimum thickness of the tile wall at top or bottom, also expressed in inches. This quotient will be the modulus of rupture of the pipe expressed in pounds per square inch.

Another type of tile-testing machine, designed by Duff A. Abrams for use in the Laboratory of Applied Mechanics of the University of Illinois, is shown in detail in Fig. 65.

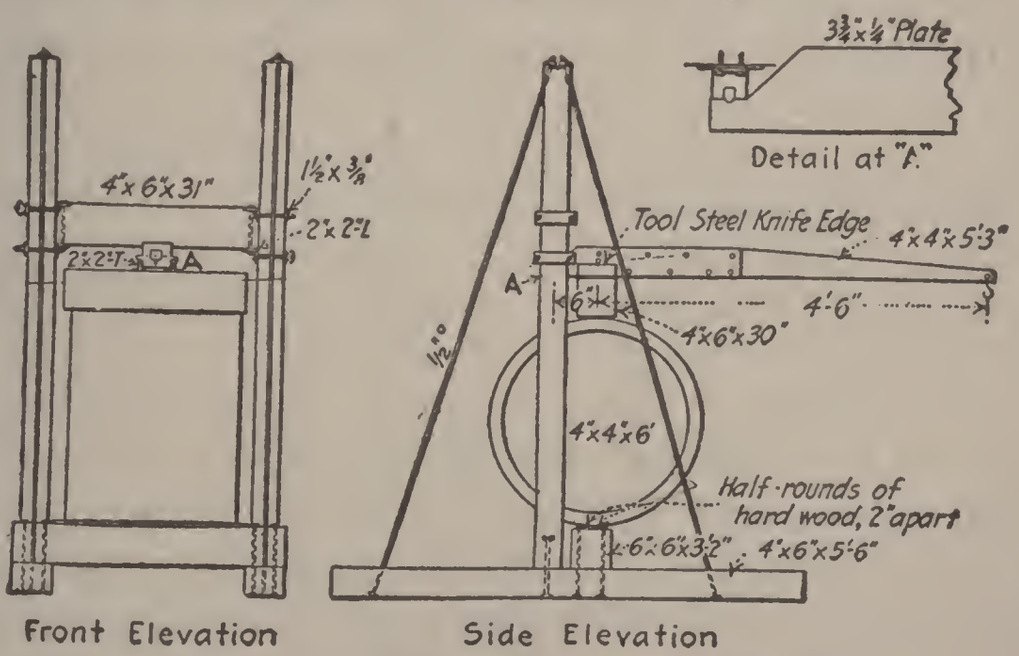


Fig. 65. Drain-Tile Testing Machine.

It consists essentially of a simple framework, and a lever for applying the load by means of dead weight. The load is applied throughout the length of the tile along the top and bottom. After the test, the weight on

the lever is determined. To obtain the breaking load on the tile, this weight is multiplied by ten, and a constant quantity is added, due to the weight of the loading lever (about 100 lbs. in this machine). The machine measures 31 in. between uprights, and will take tile up to 42 in. inside diameter.

The main members are of timber. Metal knife-edges are provided for the bearing of the loading lever on the top loading block, and for taking the upward thrust against the top cross-block. The knife-edges bearing on the block over the test tile are 5 in. c. to c., and a single knife-edge takes the end thrust. This gives considerable freedom to the top loading block, and causes the load to be applied centrally, although the top and bottom elements of the tile may not be parallel. Tiles which are out-of-round in different ways at the two ends may be readily loaded in this machine, and there is little chance for an unequal distribution of load.

The bottom loading block is provided with two small half-rounds of hardwood, placed about 2 in. apart, which allow the tile to seat itself in place. The load is applied at the top along a single element. Cushions consisting of short lengths of flattened rubber-lined fire hose are used to distribute the load along the length of the tile, and also serve to minimize the concentration of load due to irregularities of the surface of the tile.

For this kind of test, it has seemed the simplest way to fix the two strips on which the tile rests, at a definite distance apart. An analysis of rings shows that when the bearings on these strips are 2 in. apart, the resulting bending moment will be but 2½% different from that for a single support for tile 6 in. diameter, and 0.25% for a tile 12 in. diameter; while for larger sizes this variation will be much less. Under the conditions of such tests it would seem better to fix the distance for these strips, and use a common expression for the formula for the bending moment for all sizes of tile to be tested.

If desired, the modulus of rupture of the material may be determined from the dimensions of the tile and the bending moment developed by the load. It would seem that 0.16 **Qd** is a satisfactory expression for the bending moment, where **Q** is the concentrated load applied at the crown, and **d** is the mean diameter of the tile. For the modulus of rupture of the material, **f**, the formula would be:

$$f = 0.69 \frac{Qd}{l t^2},$$

where **l** is the length and **t** the average thickness of the tile along the top and bottom elements.

This method of testing was selected in preference to a method involving the bedding of the tile in sand or other material, because of its simplicity and on account of the difficulty in embedding large tile in sand in such a way as to obtain a known distribution of pressure in tests on tile of different sizes. The method of concentrated loads will give a more definite index of the strength of the material.

Our experience with this machine leads us to believe that it furnishes a satisfactory method of determining the quality of drain-tile. This machine weighs about 225 lbs. It should cost not more than $20 to $25 in a shop equipped for wood and metal working.

Tile Drainage of Land

One of the uses to which cement tile most readily lends itself is in the drainage of land. A porous tile is most advantageous for this purpose.

The main points connected with the use of tile are to determine the size of tile needed, how deep to lay these tile, and how far apart they should be placed. The size of tile is really

the last thing determined in a drainage survey, since it cannot be determined until the acreage to be drained and the slope or grade of the ditch are known. Table XXVI, compiled from Elliott's "Engineering for Land Drainage," gives sizes of tile for a given length and slope of pipe, and for a given acreage; or the table may be used to determine the acreage taken care of by a given size of pipe. In the table, it has been assumed that there is a depth of 3 feet of soil over the tile at the upper end of the line. The values given are areas from which ¼ inch of water will be removed in 24 hours by tile drains of various diameters, and lengths of 1,000 and 2,000 feet, when laid with different grades, or inches drop in a length of 100 feet. If a greater amount than ¼ inch of water is to be removed in 24 hours, reduce the number of acres given for ¼ inch by a proportionate amount. For instance, while a 6-inch tile 1,000 feet long, laid with a drop of 2 inches in 100 feet of length, will drain 34.8 acres of land of ¼ inch of water in 24 hours, this same pipe would drain only 17.4 acres of ½ inch of water in the same time.

The depths of water in the above cases are supposed to represent the effect of heavy rains upon the soil. This rainwater is assumed to be evenly distributed over the soil, and to soak into the soil at a uniform rate. It is needless to say that a compact soil will soak up the water less rapidly than a loose soil. For this reason the value of 1 inch of water per 24 hours,

TABLE XXVI

Sizes and Capacities of Drain-Pipe

Diameter of Tile (Inches)	Drop (in Inches) for each 100 Feet of Length											
	½		1		1½		2		3		6	
	Length of Drain, in Feet											
	1,000	2,000	1,000	2,000	1,000	2,000	1,000	2,000	1,000	2,000	1,000	2,000
	Acres of Land Drained of ¼ Inch of Water in 24 Hours											
5	17.3	13.5	19.1	15.7	20.6	17.6	22.1	19.4	25.1	22.7	32.0	30.3
6	27.3	21.4	29.9	24.8	32.5	27.8	34.8	30.5	39.6	35.9	50.5	47.8
7	39.9	31.4	44.1	36.4	47.7	40.8	51.1	44.8	58.0	52.8	74.0	70.1
8	55.7	43.7	61.4	50.7	66.5	57.0	71.2	62.6	80.9	73.6	103.3	98.0
9	74.7	58.8	82.2	68.1	89.1	76.3	95.3	83.8	108.4	98.6	138.1	131.3
10	96.9	76.3	106.7	88.5	115.6	99.2	123.9	108.9	140.6	128.1	179.2	170.5
12	152.2	119.9	167.7	139.3	181.7	156.2	194.6	171.6	221.1	201.8	281.8	268.6
14	222.8	175.9	245.3	204.3	265.8	229.7	284.9	251.7	323.5	296.1	412.9	393.9
16	310.2	245.0	341.4	284.6	369.5	319.7	396.3	350.4	449.9	412.2	573.7	548.8
18	414.4	328.7	456.4	381.3	494.4	428.1	529.1	470.1	601.8	552.5	767.4	735.1
20	537.6	426.9	591.5	495.8	640.4	556.6	686.3	610.5	780.0	718.2	994.5	954.6

which is assumed for loose soils, may be lowered to ½ inch in the case of soils which would retain the water longer and allow it to reach the tile more gradually.

Care should be taken to increase the size of drain-tiles as the system progresses and the drainage from larger areas of land is required to be carried by the tile. The slope to the tile should not be over 12 inches for each 100 feet of length. An average slope for common cases is 3 inches.

The spacing of tile drains for land drainage is often given as from 40 to 50 feet apart in average loam soils, and from 25 to 40 feet apart in clay soils, the depth of the tile in either case being 3½ feet or over.

The spacing and depth vary in different localities and soils. The Iowa State Drainage Association advise that for that locality, in all ordinary soils, the lateral lines or branches of tile leading to the main or trunk line be placed about 4 feet deep at the shallowest point. Such deep drainage is claimed to give better results than shallow drainage 3 feet deep, even if the branches of tile be placed from 1 to 2 rods farther apart. The general recommendation of the Association is to place the tile 3 or 4 feet deep and 100 feet apart for laterals or branches, as standard for thorough tile drainage of ordinary soil.

All tile lines should be placed parallel to the slope of the surface. If a tile drain were laid

across a slope, it would not drain that part of the land on the down side of the slope.

The "grouping" system of drainage is commonly used where sloughs or basins are encountered, as well as for ordinary wet land. This system consists of large mains running into the sloughs, with branches of smaller tile laid so as to cover the area to be drained. These laterals or branches are placed parallel, and no part of the entire area is more than a given distance from a line of tile. In some cases, the parallel lines of small tile may all empty into an open ditch. Each line is then independent and has its own outlet. The ends of these lines of tile should be protected by some form of wall or bulkhead to prevent the wearing away of the soil around the end of the pipe, and to protect it from displacement or breakage. It is well, also, to insert in the tile at the outlet a grating or a screen of woven wire, to prevent small animals entering the drain.

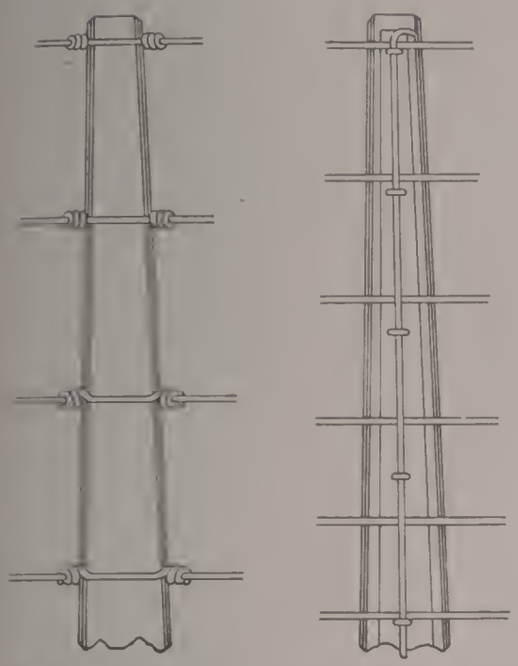
In laying out a large drainage system, there are no hard and fast rules to be followed. Short branches should be avoided, since each main drain will attend to the land for some distance on each side. The tile should be laid in as nearly straight lines as possible, and all curves should be gradual.

Where tile are to be laid in soft or treacherous ground, a bed of crushed stone should be well compacted under the drain, and the tile surrounded on all sides by a covering of crushed

stone or clean gravel. This covering may vary from 6 inches to 1 foot in thickness. The tile are laid with open joints where land drainage is desired, a common method being to pull the ordinary straight tile apart about a quarter of an inch and wrap two thicknesses of cheese-cloth around the joints to keep out the dirt while the crushed stone is being placed. When the hub-and-spigot joint is used for drainage purposes with loose joints, a piece of jute may be placed in the space between the hub and end of entering pipe.

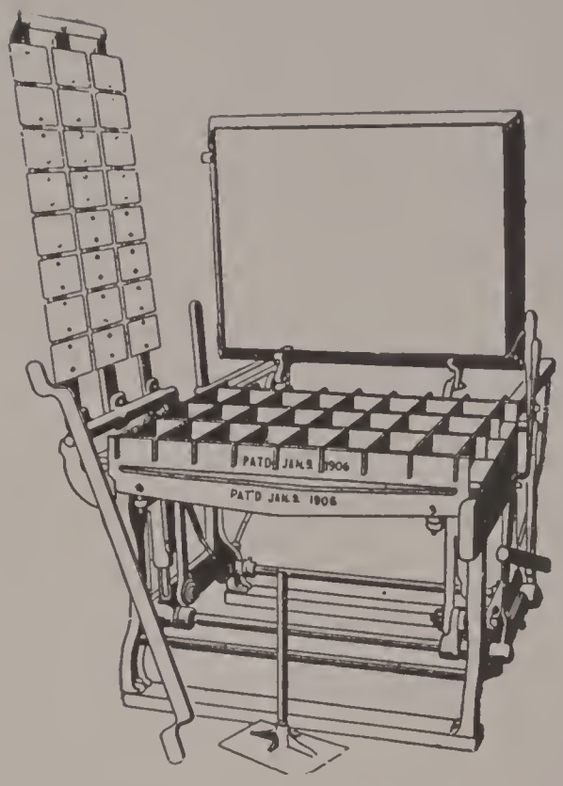
When a tight joint is desired to prevent leakage of the contained fluid, or to prevent ground water entering the line, as in the case of sewers, a tight joint is made by cementing around the joint with neat Portland cement or a 1:1 mortar of Portland cement and sand. Where tight joints are desired, the hub-and-spigot joint is made with about ½-inch space around the pipe end, in order that space may be left for a good cement joint. The length of this cement joint is about one inch greater than the thickness of pipe.

It is difficult to give figures for amounts of sand and cement needed for the various sizes of pipes and tile, since thicknesses and lengths may vary in different cases. This information is best obtained from the manufacturer of the machine used, since data of this kind is always gladly furnished upon application and may be depended upon for that particular machine.



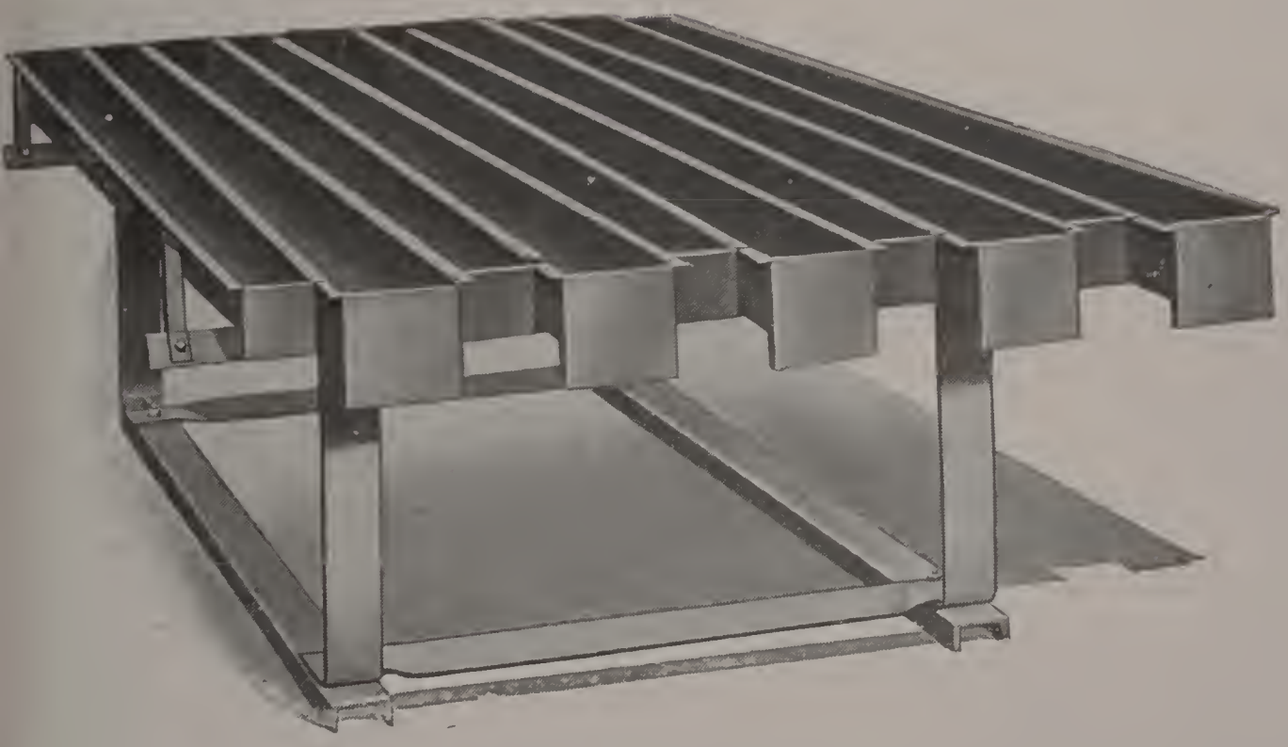
METHODS OF FASTENING FENCE WIRE TO POST.

Cut at left shows two front views (at top) and two rear views (at bottom).



CEMENT BRICK MACHINE

Hand-operated. Brick made lying flat, not on edge.



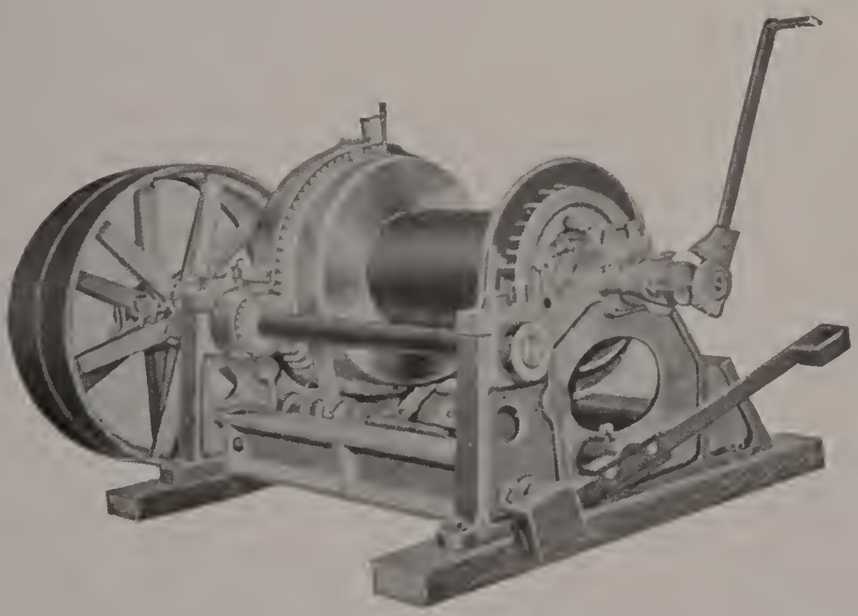
POST MOLD OUTFIT.

Adapted to any form of reinforcement or method of attaching fence.

PUBLIC COMFORT STATION, CENTRAL PARK, LOS ANGELES, CAL.

View looking northwest. Entrance at extreme left leads to tool-house of park gardener; second entrance is to stairs down to men's section; railing in distance surrounds entrance to ladies' section. In middle distance is circular ventilator shaft, from which air is exhausted so rapidly that no odor is perceptible to passers-by.

CONTRACTOR'S SELF-RIGHTING AND BOTTOM-DUMP BUCKETS.



SINGLE-DRUM BELT HOIST.

BAR BENDER.
For bending reinforcing bars for concrete work.

CONCRETING WHEELBARROW.
Frame built of tubular steel. Note bracing of tray.

Rules for operating each type of tile machine are also furnished, and should be carefully followed.

A farmer expects to paint or repair his buildings at regular intervals, and fortunately can get at these places that need repair without difficulty. But the farmer who deliberately buries a material at a depth of four feet under an entire field, knowing that his great-grandchildren will receive the same benefit from his labor that he is to receive, creates at one operation an everlasting legacy both for himself and his descendants.

CEMENT SHINGLE MACHINES

Cement shingles are made in a variety of forms—diamond shaped, oblong, etc. Some are flat, with grooved interlocking sides; others are corrugated, with double-grooved interlocking sides; one type has tapering ribs extending to above the middle of the shingle, convex on the upper side and concave on the under side, the shingles overlapping to the middle of the next lower course so that any water entering through the cracks between the shingles is confined to the valley between the ribs.

Different methods of laying cement shingles are adopted. In some cases they are fastened by means of nails or screws driven through perforations provided for the purpose. In other cases, small pieces of asbestos fabric are embedded in the shingles, being sufficiently flexible

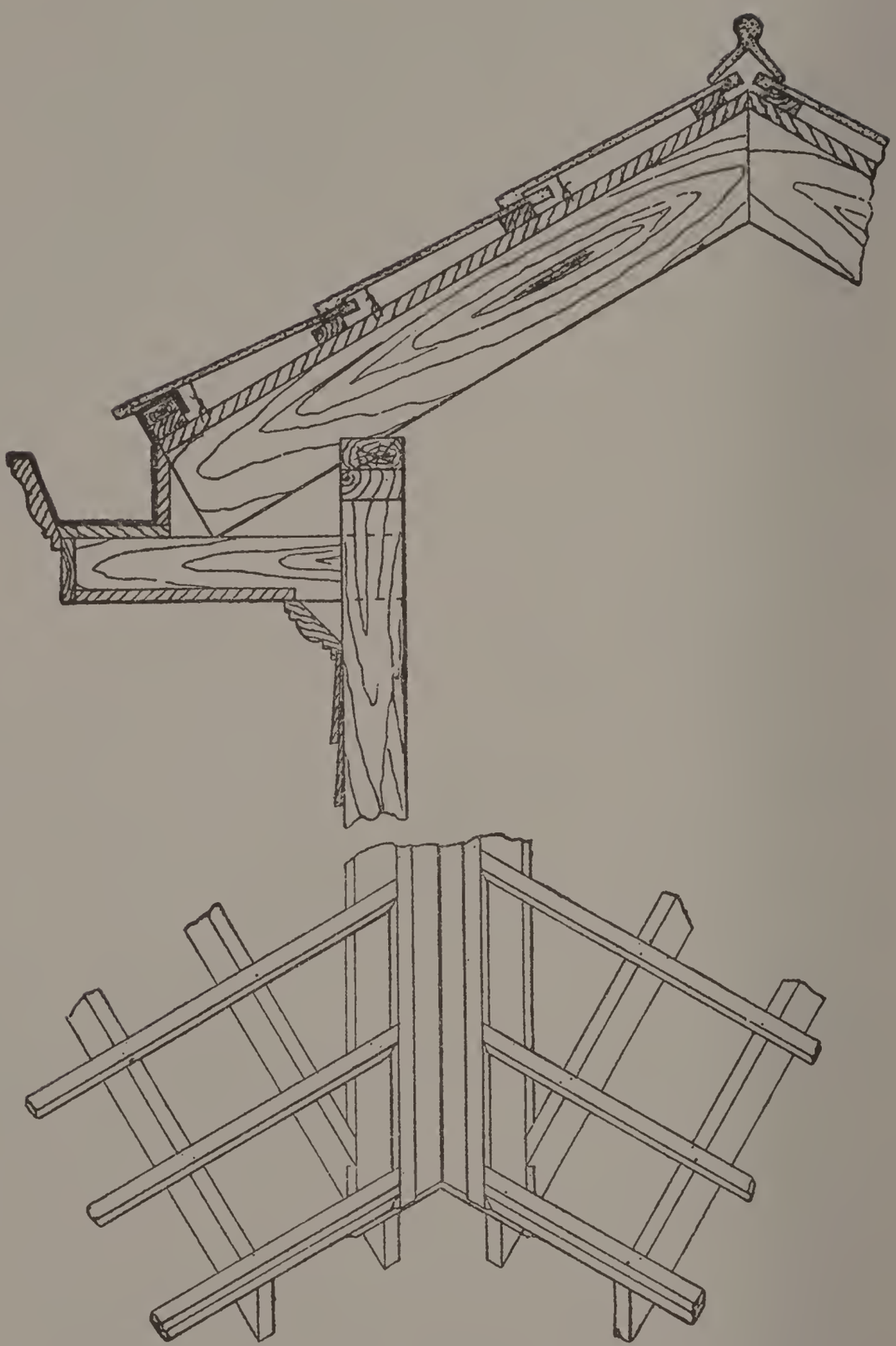


Fig. 66. Laying One Type of Concrete Shingles.

Upper figure shows closed roof construction; lower figure, preparation of valley for open-roof construction.

to allow nails to be driven through them without cracking the shingles. In still other cases each shingle is provided with a copper wire embedded near the lower end, to be securely wrapped around a nail driven in a cleat or in the roof sheathing (see Fig. 66).

MISCELLANEOUS DATA

Portland Cement Industry. A graphic illustration of the remarkable growth of the Portland Cement Industry in the United States, as compared with the advances made in other industrial lines, is given in the accompanying chart (Fig. 67), prepared in the Birkinbine Engineering Offices, Philadelphia. The curves also afford comparison with the increase in population, monetary circulation, etc.

Beginning at the bottom of the chart with less than a million barrels in 1890, the cement line is gradual in its rise until 1896, when its upward tendency becomes pronounced, advancing with such rapidity that it soon crosses that of pig iron, extending far beyond all comparative lines, and finally ending in the great total of fifty million barrels in 1908. It is entirely unique in that it does not show the least downward tendency at any point, a record no other industry has made. (See also page 12.) A similar record of growth has characterized the industry since 1908, when the diagram of Fig. 67 was prepared. Following are the figures of production for the period 1909-1913:

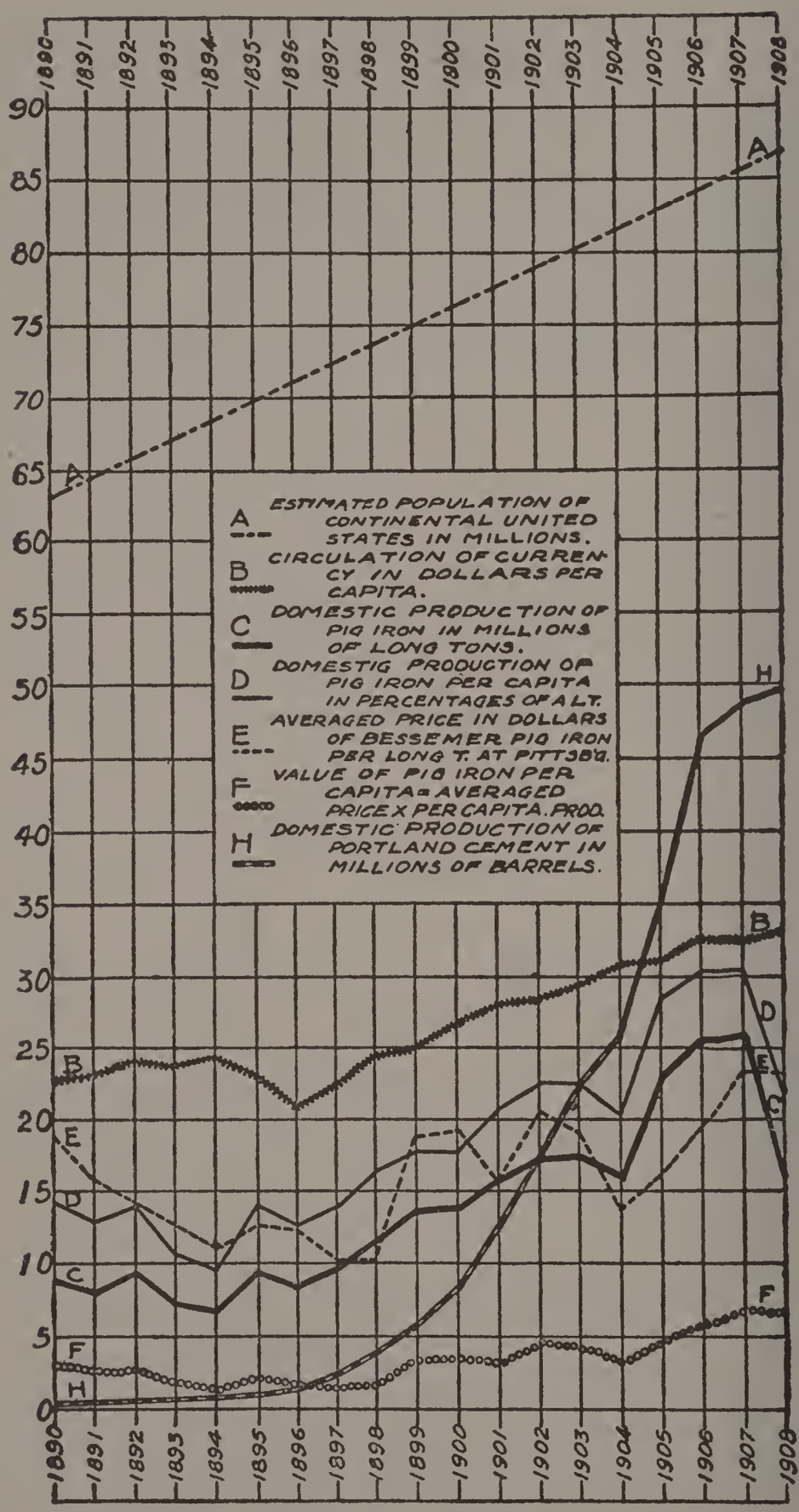


Fig. 67. Diagram Showing Remarkable Advance of Portland Cement Manufacturing Industry as Compared with Other Industrial Features of the United States.

Year.	No. Bbls.	Value.	Mill Price per Bbl.
1909	64,991,431	$52,858,354	$0.813
1910	76,549,951	68,205,800	.891
1911	78,528,637	66,248,817	.844
1912	82,438,096	67,022,172	.813
1913	92,097,131	.....	1.005

Table XXVII, compiled by the United States Geological Survey, gives a comparative statement of production and shipments for 1912 and 1913, by commercial districts.

TABLE XXVII

Production (P) and Shipments (S) of Portland Cement in 1912 and 1913, by Commercial Districts

District.		Active plants.		Production and shipments (barrels).			Average factory price per barrel.		
		1912	1913	1912	1913	Percentage of change, 1913.	1912	1913	Percentage of change, 1913.
Lehigh district (New Jersey, and eastern Pennsylvania)	P..	22	22	24,762,083	27,139,601	+ 9.60	.....	.....	.....
	S..	25	22	26,013,891	26,659,537	+ 2.48	$0.674	$0.838	+24.33
New York	P..	7	8	4,492,806	5,208,020	+15.92	.....	.....	.....
	S..	7	8	4,543,060	5,136,334	+13.05	.759	.934	+23.05
Ohio and western Pennsylvania	P..	9	9	7,359,402	2,690,010	+ 4.49	.....	.....	.....
	S..	9	9	7,398,753	7,287,028	— 1.51	.757	1.000	+32.10
Michigan and northeastern Indiana	P..	13	13	4,308,645	5,057,199	+ 1.73	.....	.....	.....
	S..	13	13	4 417,808	4,960,891	+ 1.22	.851	1.030	+21.03
Kentucky and southern Indiana	P..	3	3	3,091,603	3,005,417	— 2.78	.....	.....	.....
	S..	3	3	3,134,841	2,861,624	— 8.71	.764	1.008	+31.93
Illinois and northwestern Indiana	P..	6	6	10,659,357	12,423,799	+16.55	.....	.....	.....
	S..	6	6	10,677,479	11,576,938	+ 8.42	.744	1.002	+34.67
Maryland, Virginia and West Virginia	P..	4	4	2,325,885	2,668,338	+14.72	.....	.....	.....
	S..	5	4	2,536,546	2,529,629	— .27	.726	.865	+19.14
Tennessee, Alabama, and Georgia	P..	5	5	2,411,372	3,082,623	+27.83	.....	.....	.....
	S..	6	5	2,544,663	2,958,829	+16.27	.746	.899	+20.50
Iowa and Missouri	P..	8	8	7,583,933	8,427,012	+11.11	.....	.....	.....
	S..	8	8	7,804,901	7,941,620	+ 1.75	832	1.074	+29.08
Great Plains States (Kansas, Oklahoma, and central Texas)	P..	15	15	5,807,043	6,350,646	+ 9.36	.....	.....	.....
	S..	17	15	6,174,085	6,190,140	+ .26	866	1.063	+22.75
Rocky Mountain States [a] (Colorado) Utah, Montana, and western Texas)	P..	7	[a] 8	2,299,252	[a] 2,546,082	+10.73	.....	.....	.....
	S..	7	[a] 8	2,234,602	[a] 2,545,473	+13.91	1.165	[a] 1.319	+13.21
Pacific coast States (California and Washington)	P..	11	12	7,336,715	8,498,384	+15.83	.....	.....	.....
	S..	11	12	7,531,927	8,041,434	+ 6.76	1.358	1 461	+ 7.58
Total	P..	110	113	82,438,096	92,097,131	+11 72	.....	.....	.....
	S..	117	113	85,012,556	88,689,377	+ 4.31	$0 813	$1 005	+23.62

[a] Includes Arizona in 1913.

Mineral Wool. For purposes of fireproofing, insulation against temperature changes, sound-

proofing, etc., mineral wool is a material of construction that has come into extensive use in recent years. It is a mineral substance of a vitreous nature, in physical form consisting of a mass of fine fibers of irregular thickness interlacing one another in every direction and thus inclosing innumerable minute air cells. Chemically, it is a silicate of magnesia, lime, alumina, potash, and soda. The name **Silicate Cotton** is sometimes applied to it.

Mineral wool is manufactured by converting scoria or slag, together with certain rocks, while in a melted condition, to a fibrous state. It partakes of the nature of glass without its brittleness, the fibers being soft, pliant, and inelastic. On account of the large proportion of air which it holds in confinement, it possesses a remarkable power of resisting the transmission of heat and cold, and hence is of value as a means of frost-proofing and of insulation against heat.

Mineral wool is non-combustible and practically indestructible by heat; hence has important value as a fireproofing material. If properly placed, it goes far to reduce the fire-risk in buildings. Even when constructed chiefly of wood, a building may be made to burn very slowly by the use of mineral wool. Wire lath and expanded metal may be used in connection with the filling of mineral wool between the studding and floor joists.

As a non-conductor of sound, mineral wool also has special value, and hence makes a very

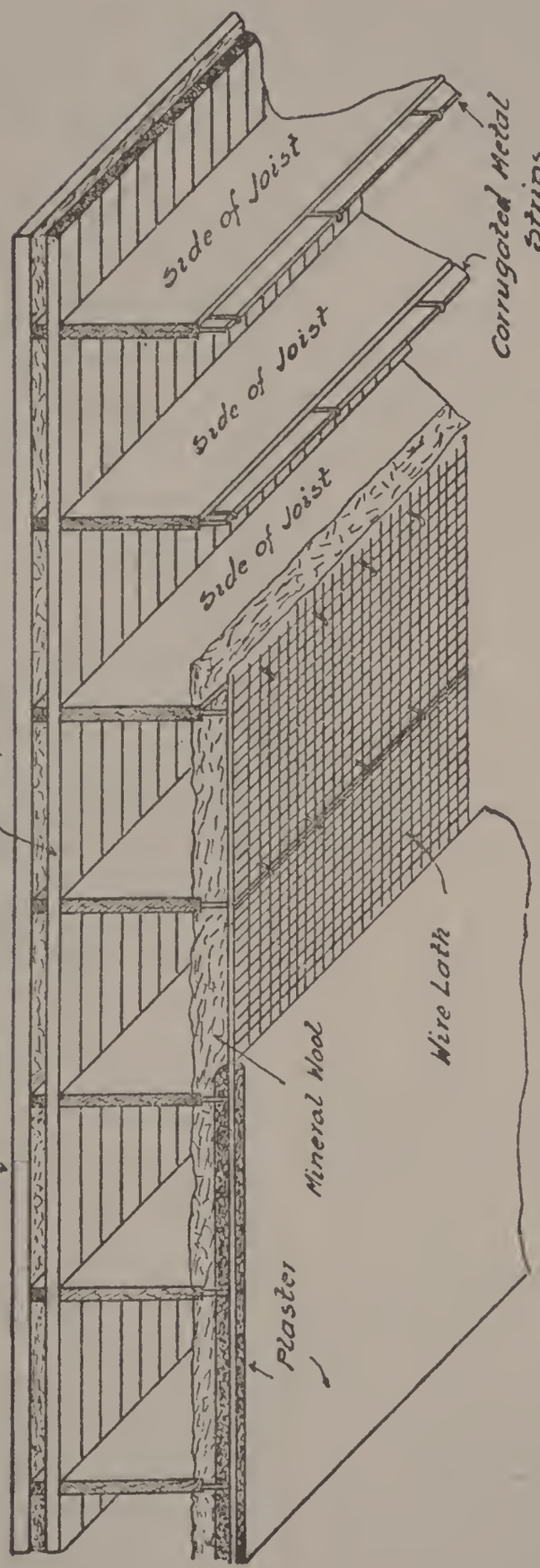


Fig. 68. Diagram Showing Method of Using Mineral Wool for Semi-Fireproof Construction of Ceiling.

efficient "deadener" or "deafener" of the floors, walls, and partitions of buildings.

Various methods of applying this material to construction work are illustrated in Figs. 68,

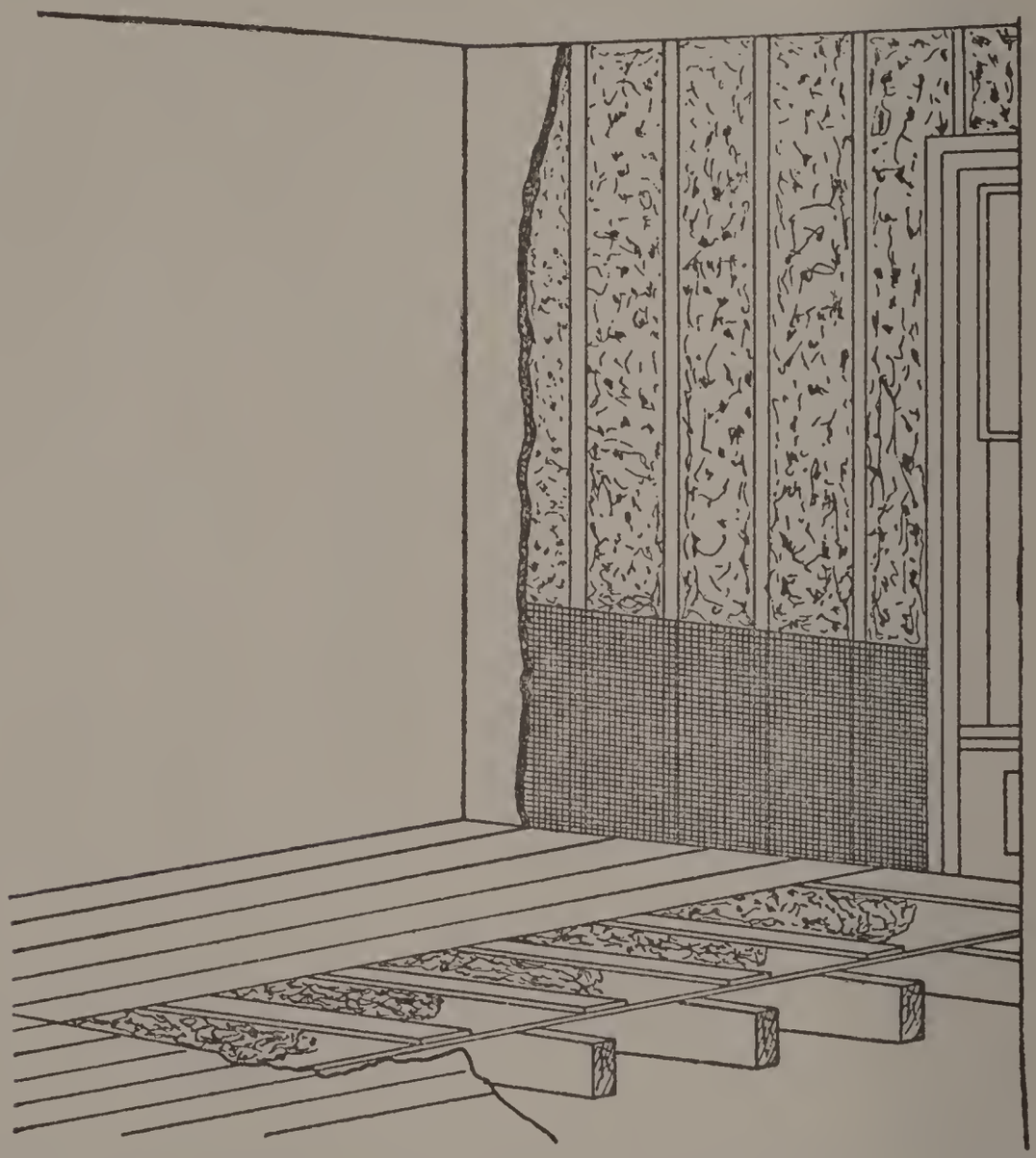


Fig. 69. **Method of Using Mineral Wool in Floors and behind Wire Lath in Walls.**

69, and 70. In floors, the plan which gives the best result is to cover the joist with a rough floor, upon which lay wood strips to support the upper or finished floor. These strips should be at least a quarter of an inch thicker than the

desired depth of wool. The mineral wool is packed between strips before the upper floor is laid. Another plan is to put a rough sub-floor between the joists, pack in the wool, and lay the finished floor upon the joists. Both modes are shown in the accompanying illustrations (Figs. 68 and 69). If strips of fireproof asbestos paper are put under the wood strips in the first mode, or upon top of the joists in second plan, it will help to prevent the transmission of sound through the woodwork. The wool should not be trampled upon after being put in place.

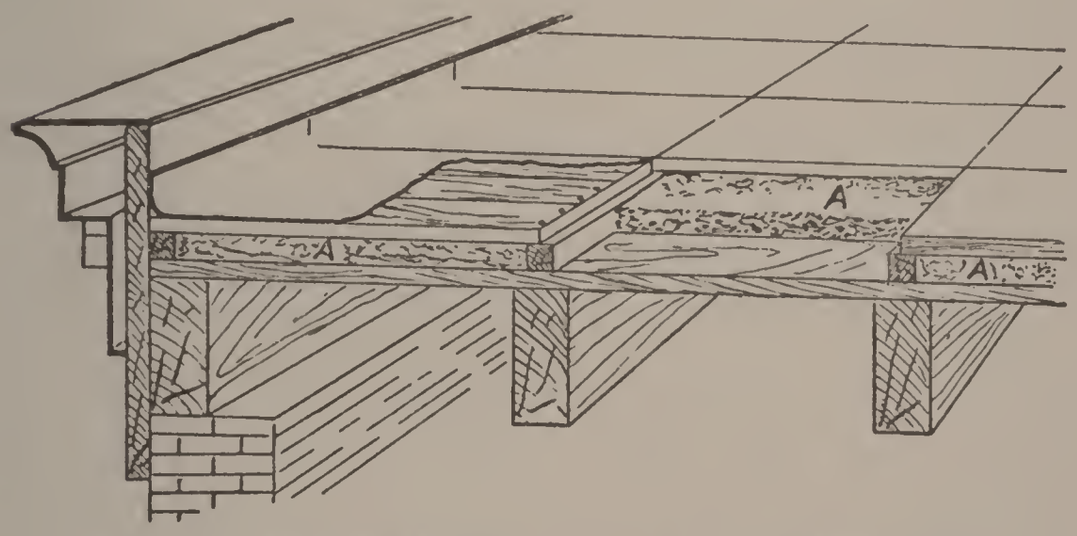


Fig. 70. Use of Mineral Wool for Roof Insulation.

Placed under the roof boards as shown at A, A, A, mineral wool assists greatly in rendering upper rooms comfortable in summer or winter.

In walls and partitions, the wool should be put in at the same time the laths are being put on. Begin lathing at the floor, with either wood or wire lath. After lathing up two or three feet, fill in the wool as high as lathed, then a few feet more of lath, and fill up as before, until the top is reached (see Fig. 69).

In using wool for insulation or deafening, in connection with brick walls or partitions, furring strips can be used, and the wool packed in two inches thick behind the lath.

In roofs the mineral wool can be packed between the rafters by sheathing underneath them, beginning at the eaves and working toward the ridge, packing in the wool as the sheathing is done. A minimum thickness of two inches will be found very effective in making the rooms comfortable that are next to the roof (see Fig. 70).

A high grade of mineral wool, combined with degummed flax fiber to give it strength, is manufactured into board form for insulating purposes.

The well-known fibrous rock, **asbestos**, is also manufactured in a variety of forms and combinations with other materials, for similar purposes; and there are also on the market a great number of special, patented, insulating materials in board and fabric forms, comprising felt, combinations of felt with building paper or plaster, or of wood with gypsum products, etc. Fig. 69 gives some suggestions as to the manner of using various insulating materials in the construction of partition walls.

For fireproofing interior walls, veneering floors, etc., a form of concrete known as **pulp concrete** is sometimes used. This is simply concrete in which wood pulp or sawdust is used as the aggregate mixed with the sand and

cement. This form of concrete is never employed for outdoor work. It is of low tensile strength, and is much lighter than ordinary concrete. On account of its elasticity, combined with its practically non-absorbent character, it is especially used as a floor veneering for saloons, markets, butcher shops, etc. It may be laid without joints in a continuous layer 1½ inches deep, upon paper spread over the floor that is being treated. The customary proportions for mixing are 1 part cement, 2 parts sand, and 2½ parts pulp or sawdust. If an excess of pulp is used, the concrete becames absorbent.

Glass Brick. A combination of glass and concrete has recently been developed for construction work, in the shape of brick consisting of glass moulded into various hollow shapes and filled with concrete. Forms for casting these bricks in various shapes are illustrated in Fig.

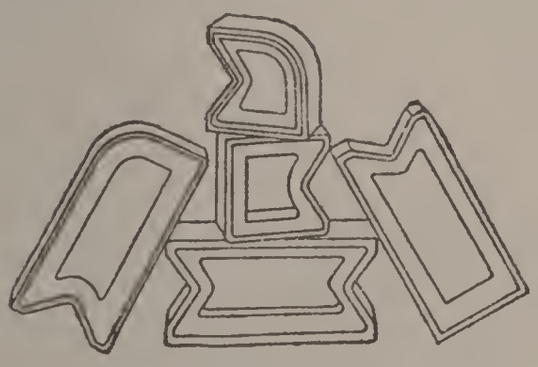


Fig. 71. Forms for Casting Glass Bricks.

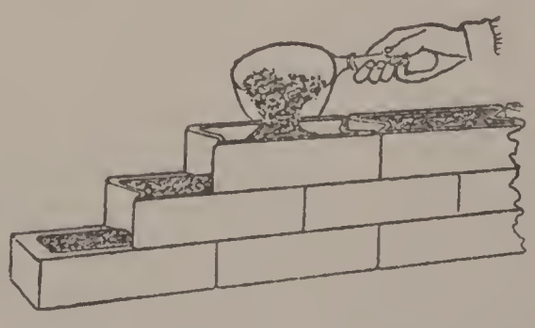


Fig. 72. Pouring Glass Brick. Showing also method of wall construction.

71, while Fig. 72 shows method of pouring them full of concrete, also one manner of laying them in wall construction. The bricks have indented

ends, and may be laid up with narrow mortar joints, when desired. The construction is said to be remarkably free from tendency to open joints from settling, and is also claimed to be waterproof.

How to Make Cement Mortar Adhere. Some contractors have difficulty in causing cement mortar to adhere to finished cement work, and to stone and brick work. To do this properly, soak the surface of the old work thoroughly with water, dust on a little neat cement, and follow this with a mortar coat before the dusted cement has set. Or apply a thick paint of neat cement and water to the old work after the work has been thoroughly soaked; this paint forms a binder; apply mortar coat promptly, before the coating of neat cement paint has set.

For Ready Reference. The following miscellaneous data may frequently be found of value for ready reference in solving problems, making estimates, settling disputed questions, etc.:

1,728 cu. in. make 1 cu. ft.

27 cu. ft. make 1 cu. yd.

1 lb.=27.681 cu. in. of distilled water.

A gal. of water at 62° Fahrenheit weighs 8.3356 lbs.

A cu. ft. contains 7.4805 gals. at 62° Fahrenheit.

To find the diameter of a circle, multiply circumference by .31831.

To find circumference of a circle, multiply diameter by 3.1416.

To find area of a circle, multiply square of diameter by .7854; or multiply radius (one-half diameter) by circumference, and divide product by 2 (see Table XXVIII).

TABLE XXVIII

Areas of Circles of Different Diameters

Diameter	Area	Diameter	Area	Diameter	Area	Diameter	Area
⅛	0.0123	10	78.54	30	706.86	65	3318.3
¼	0.0491	10½	86.59	31	754.76	66	3421.2
⅜	0.1104	11	95.03	32	804.24	67	3525.6
½	0.1963	11½	103.86	33	855.30	68	3631.6
⅝	0.3068	12	113.09	34	907.92	69	3739.2
¾	0.4418	12½	122.71	35	962.11	70	3848.4
⅞	0.6013	13	132.73	36	1017.8	71	3959.2
1	0.7854	13½	143.13	37	1075.2	72	4071.5
1⅛	0.9940	14	153.93	38	1134.1	73	4185.4
1¼	1.227	14½	165.13	39	1194.5	74	4300.8
1⅜	1.484	15	176.71	40	1256.6	75	4417.8
1½	1.767	15½	188.69	41	1320.2	76	4536.4
1⅝	2.073	16	201.06	42	1385.4	77	4656.6
1¾	2.405	16½	213.82	43	1452.2	78	4778.3
1⅞	2.761	17	226.98	44	1520.5	79	4901.6
2	3.141	17½	240.52	45	1590.4	80	5026.5
2¼	3.976	18	254.46	46	1661.9	81	5153.0
2½	4.908	18½	268.80	47	1734.9	82	5281.0
2¾	5.939	19	283.52	48	1809.5	83	5410.6
3	7.068	19½	298.64	49	1885.7	84	5541.7
3¼	8.295	20	314.16	50	1963.5	85	5674.5
3½	9.621	20½	330.06	51	2042.8	86	5808.8
3¾	11.044	21	346.36	52	2123.7	87	5944.6
4	12.566	21½	363.05	53	2206.1	88	6082.1
4½	15.904	22	380.13	54	2290.2	89	6221.1
5	19.635	22½	397.60	55	2375.8	90	6361.7
5½	23.758	23	415.47	56	2463.0	91	6503.9
6	28.274	23½	433.73	57	2551.7	92	6647.6
6½	33.183	24	452.39	58	2642.0	93	6792.9
7	38.484	24½	471.43	59	2733.9	94	6939.8
7½	44.178	25	490.87	60	2827.4	95	7088.2
8	50.265	26	530.93	61	2922.4	96	7238.2
8½	56.745	27	572.55	62	3019.0	97	7389.8
9	63.617	28	615.75	63	3117.2	98	7542.9
9½	70.882	29	660.52	64	3216.9	99	7697.7

To find the surface of a ball, multiply square of diameter by 3.1416.

To find side of a square approximately equal in area to a given circle, multiply diameter by .8862.

To find cubic inches in a ball, multiply cube of diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

Double riveting is from 16 to 20 per cent stronger than single.

One ton of coal is equivalent to two cords of wood for steam purposes.

There are nine square feet of heating surface to each square foot of grate surface.

A cubic foot of water weighs approximately 62½ lbs.

A cubic foot of ice weighs approximately 55½ lbs.

Each nominal horse-power of a boiler requires 30 to 35 lbs. of water per hour.

To sharpen dull files, lay them in diluted sulphuric acid until they are eaten deep enough.

A horse-power is equivalent to raising 33,000 lbs. one ft. per minute, or 550 lbs. one ft. per second.

The average consumption of coal for steam boilers is 12 lbs. per hour for each sq. ft. of grate surface.

Steam rising from water at its boiling point (212 degrees) has a pressure equal to the atmosphere (14.7 lbs. to the square inch).

To evaporate one cubic foot of water requires the consumption of 7½ lbs. of ordinary coal, or about 1 lb. of coal to 1 gallon of water.

One-sixth of the tensile strength of a plate, multiplied by the thickness of the plate and divided by one-half the diameter of the boiler, gives the safe working pressure for tubular boilers. For marine boilers, add 20 per cent for drilled holes.

No plates or bars of either steel or iron should be worked at a black or blue heat (say, about 500°); the material will stand far more strain either red hot or cold, while at an intermediate point great risks will be run, and possibly strains produced which result in rupture later on.

One thousand shingles, laid four inches to the weather, will cover one hundred square feet of surface, and five lbs. of shingle nails will fasten them on.

One-fifth more siding and flooring is needed than the number of square feet of surface to be covered, because of the lap in siding and flooring.

One thousand laths will cover seventy yards of surface, and eleven pounds of lath nails will be required to nail them on.

Eight bushels of good lime, sixteen bushels of sand,

and one bushel of hair will make enough good mortar to plaster 100 square yards.

One cord of stone, three bushels of lime, and a cubic yard of sand will lay one hundred cubic feet of wall.

Cement one bushel, and sand two bushels, will cover 3½ square yards one inch thick; 4½ square yards ¾ inch thick; or 6¾ square yards ½ inch thick.

One bushel of cement and one bushel of sand will cover 2¼ square yards one inch thick; 3 square yards ¾ inch thick; or 4½ square yards ½ inch thick.

One bushel of anthracite coal weighs from 75 to 80 lbs. One bushel of bituminous coal weighs from 70 to 75 lbs. One bushel of coke weighs 32 lbs. A pound of anthracite coal contains 14,500 heat units.

To find approximately the amount of paint required to cover a given surface, divide the number of square feet of surface by 200. The result will be the number of gallons of liquid paint required to give two coats. Or divide by 18, and the result will be the number of pounds of pure ground white lead required to give three coats.

Weight of Materials. The approximate weight per cubic foot of materials commonly used in construction is as follows:

Material	Weight per Cubic Foot Lbs.
METALS	
Bronze	552
Copper	550
Iron, cast	450
Iron, wrought	480
Lead	712
Steel, structural	490
TIMBER	
	Lbs.
Cedar	23
Chestnut	41
Cypress	29

Fir	32
Hemlock	25
Oak, white	50
Pine, white	24
Pine, yellow	35
Spruce	25

MASONRY

	Lbs.
Asphalt	130
Blue stone	160
Brick in lime	120
Brick in cement	130
Cement, Portland	94
Concrete	150
Gneiss	160
Granite	165
Gravel	120
Limestone	170
Marble	165
Sandstone	145
Slate	170
Terra-Cotta	110
Tile	115

Weight of a bag of natural cement, 88 to 100 lbs. (3 bags to a barrel).

Weight of a bag of Portland cement, about 95 lbs. (4 bags to a barrel).

A bbl. of natural cement=3 bags, and weighs from about 265 to about 300 lbs., varying in different localities.

A bbl. of Portland cement=4 bags, and weighs about 380 lbs.

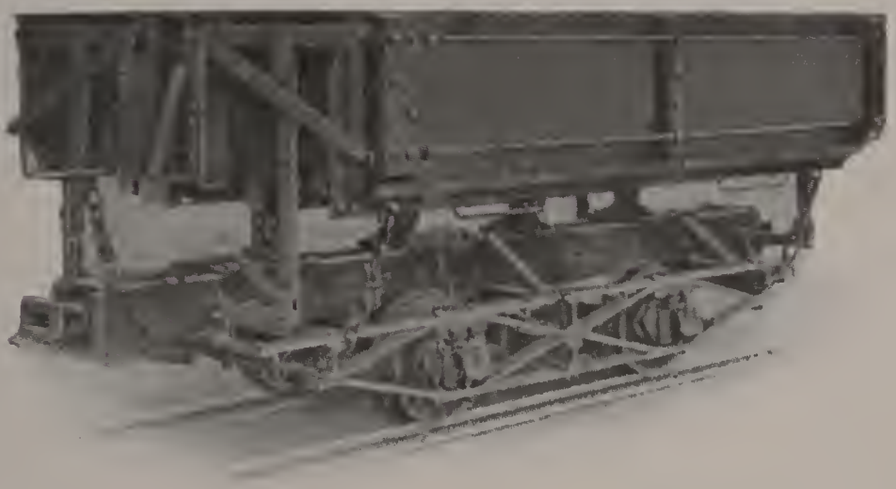
A cu. ft. of loose measured broken trap stone weighs about 90 lbs.

A cu. ft. of broken stone, well shaken down, weighs about 100 lbs.

A cu. ft. of crusher-run stone weighs about 100 lbs.

A cu. ft. of cinder concrete averages 110 lbs.

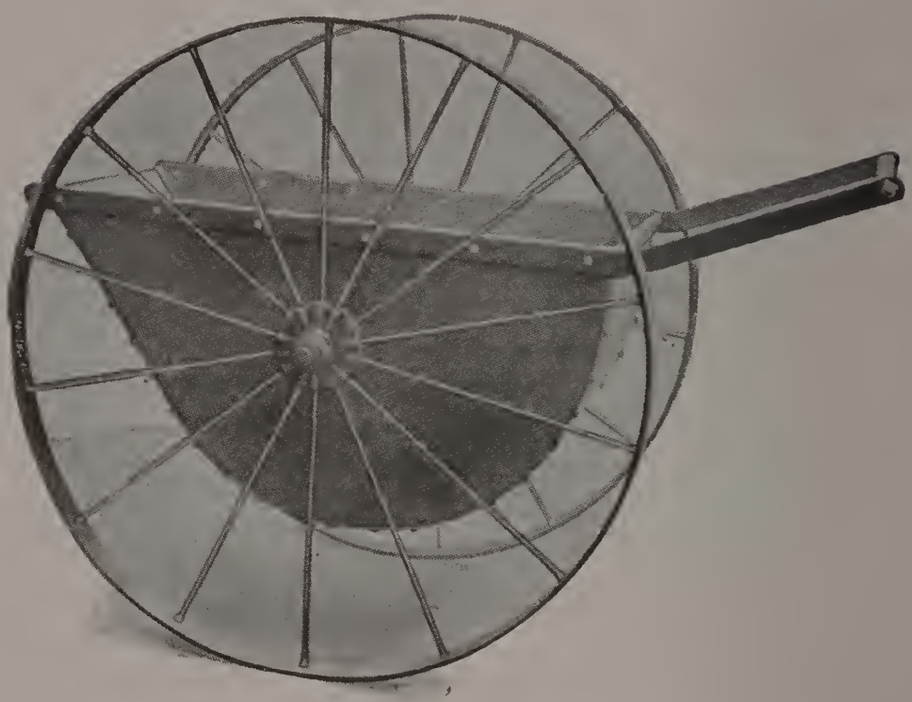
TROY DUMP WAGON.



CONCRETE TWO-WAY DUMP CAR.

CONTRACTOR'S TWO-WAY DUMP CAR.

CONCRETE WHEELBARROW.



CONCRETE HAND CART.

CONCRETE CART.

Dumped by releasing spring clip, handle and legs remaining stationary.

A cu. ft. of conglomerate concrete averages 130 lbs.

A cu. ft. of gravel concrete averages 150 lbs.

A cu. ft. of limestone concrete averages 148 lbs.

A cu. ft. of sandstone concrete averages 143 lbs.

A cu. ft. of trap concrete averages 155 lbs.

Loose, unrammed concrete weighs from 5 to 25 per cent less than when well tamped.

One cubic foot of anthracite coal weighs about 58 lbs.

One cubic foot of bituminous coal weighs from 47 to 50 lbs.

Specific Gravity of Stone

Trap, Boston, Mass	2.78	Limestone (oolitic), Bedford, Ind.	2.25 to 2.45
Trap, Duluth, Minn	2.8 to 3.0	Limestone, Marquette, Mich.	2.34
Trap, Jersey City, N. J.	3.03	Limestone, Glens Falls, N. Y.	2.70
Trap, Staten Island, N. Y.	2.86	Limestone, Lake Champlain, N. Y.	2.75
Gneiss, Madison Ave., N. Y.	2.92	Sandstone, Portland, Conn.	2.64
Granite, New London, Conn.	2.66	Sandstone, Haverstraw, N. Y.	2.13
Granite, Greenwich, Conn.	2.84	Sandstone, Medina, N. Y.	2.41
Granite, Vinalhaven, Me.	2.66	Sandstone, Potsdam, N. Y.	2.60
Granite, Quincy, Mass.	2.66	Sandstone (grit), Berea, O.	2.12
Granite, Barre, Vt.	2.65		
Limestone, Joliet, Ill.	2.56		
Limestone, Quincy, Ill.	2.51 to 2.57		

Specific Gravity of Common Minerals and Rocks

Apatite	2.92—3.25	Limestone	2.35—2.87
Basalt	3.01	Magnetite, Fe_3O_4	4.9 —5.2
Calcite, $CaCO_3$	2.5 —2.73	Marble	2.08—2.85
Cassiterite, SnO_2	6.4 —7.1	Mica	2.75—3.1
Cerusite, $PbCO_3$	6.46—6.48	Mica Schist	2.5 —2.9
Chalcopyrite, $CuFeS_2$	4.1 —4.3	Olivine	3.33—3.5
Coal, anthracite	1.3 —1.84	Porphyry	2.5 —2.6
Coal, bituminous	1.2 —1.5	Pyrite, FeS_2	4.83—5.2
Diabase	2.6 —3.03	Quartz, SiO_2	2.5 —2.8
Diorite	2.92	Quartzite	2.6 —2.7
Dolomite, $CaMg(CO_3)_2$	2.8 —2.9	Sandstone	2.0 —2.78
Feldspar	2.44—2.78	Sandstone, Medina	2.4
Felsite	2.65	Sandstone, Ohio	2.2
Galena, PbS	7.25—7.77	Sandstone, Slaty	1.82
Garnet	3.15—4.31	Shale	2.4 —2.8
Gneiss	2.62—2.92	Slate	2.5 —2.8
Granite	2.55—2.86	Sphalerite, ZnS	3.9 —4.2
Gypsum	2.3 —3.28	Stibnite, Sb_2S_3	4.5 —4.6
Halite (salt), NaCl	2.1 —2.56	Syenite	2.27—2.65
Hematite, Fe_2O_3	4.5 —5.3	Talc	2.56—2.8
Hornblende	3.05—3.47	Trap	2.6 —3.0
Limonite, $Fe_3O_4(OH)_6$	3.6 —4.0		

Table XXIX shows the weights of aggregates of varying specific gravity and having different percentages of voids.

Bearing Power of Soils. Table XXX gives the bearing power of various soils, and will be found of use in calculations for footings, foundations, etc.

TABLE XXIX

Weights of Aggregates of Varying Specific Gravity and Percentages of Voids

Specific Gravity	Weight in Pounds per Cu. Ft.	Weight in Pounds per Cu. Yd.	Weight in Pounds per Cu. Yd. when Voids are				
			30%	35%	40%	45%	50%
1.0	62.355	1,684	1,178	1,094	1,010	926	842
2.0	124.7	3,367	2,357	2,187	2,020	1,852	1,684
2.1	130.9	3,536	2,475	2,298	2,121	1,945	1,768
2.2	137.2	3,702	2,593	2,408	2,222	2,037	1,852
2.3	143.4	3,872	2,711	2,517	2,323	2,130	1,936
2.4	149.7	4,041	2,828	2,626	2,424	2,222	2,020
2.5	155.9	4,209	2,946	2,736	2,525	2,315	2,105
2.6	162.1	4,377	3,064	2,845	2,626	2,408	2,189
2.7	168.4	4,545	3,182	2,955	2,727	2,500	2,273
2.8	174.6	4,714	3,300	3,064	2,828	2,593	2,357
2.9	180.9	4,882	3,418	3,174	2,929	2,685	2,441
3.0	187.1	5,051	3,536	3,283	3,030	2,778	2,526
3.1	193.3	5,219	3,653	3,392	3,131	2,871	2,609
3.2	199.5	5,388	3,771	3,502	3,232	2,963	2,614
3.3	205.8	5,556	3,889	3,611	3,333	3,056	2,778
3.4	212.0	5,724	4,007	3,721	3,434	3,148	2,862
3.5	218.3	5,893	4,125	3,830	3,535	3,241	2,947

TABLE XXX

Bearing Power of Various Soils

Kind of Material	Bearing Power in Tons per Sq. Ft.	
	Min.	Max.
Rock—the hardest—in thick layers of native bed	200	..
Rock equal to best ashlar masonry	25	30
Rock equal to best brick masonry	15	20
Rock equal to poor brick masonry	5	10
Clay on thick beds, always dry	4	6
Clay on thick beds, moderately dry	2	4
Clay, soft	1	2
Gravel and coarse sand, well compacted	8	10
Sand, compacted and well cemented	4	6
Sand, clean, dry	2	4
Quicksand, alluvial soils, etc	0.5	1

Water. Water is a chemical compound of two gases—hydrogen and oxygen—2 volumes of hydrogen and 1 volume of oxygen, or 2 parts of hydrogen and 16 parts of oxygen by weight. It is never found absolutely pure in nature, because it is the best solvent known and absorbs or dissolves impurities from the air and soil. Water boils under atmospheric pressure of 14.7 lbs. per sq. in., at the elevation of Chicago, at 212° F., and passes off as steam. Water expands when heated, so that its greatest density

is at a temperature of 39.1° F. (4° C.), when it weighs 62.425 lbs. per cubic foot (7½ gallons). Below 39.1° F. to freezing point (32° F. or 0° C.), its density remains practically unchanged.

Water has the greatest specific heat (capacity for heat) of any known liquid or substance. It is incompressible by pressure, but expands with heat and decreases in density; that is, the same weight of water will occupy a larger volume with increase of temperature.

One pound of water evaporated to steam at atmospheric pressure requires 966.1 heat units (B. T. U.).

Water increases 1,646 times its original volume on conversion to steam at the same pressure. It increases suddenly about one-eighth of its volume on freezing, exerting tremendous force.

One gallon (U. S. Standard) of water at 39.1° F. weighs 8 lbs. 5⅓ oz., and contains 231 cu. in.

One foot of water column at 39.1° F.=62.425 lbs. on the sq. ft.; or 0.4335 lb. on the sq. in.; or 0.0295 atmosphere, or 0.8826 in. of mercury, at 32° F.

One atmosphere equals the weight of a water column 1 in. square and 33.9 ft. high.

One atmosphere equals the weight of a mercury column 29.92 in. high.

One inch of mercury column at 32° F. equals 1.133 ft. of water column.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by .434. Approximately every foot of elevation is equal to one-half pound pressure per inch.

Air. Air consists of a mechanical mixture of gases, principally nitrogen and oxygen, in the ratio of 20.7 volumes of the former to 79.3 volumes of the latter; and by weight, of 23 parts of nitrogen to 77 parts of oxygen. Air in its natural state contains small quantities of other gases—CO_2 (carbon dioxide or carbonic acid gas), water vapor, ammonia, argon, helium, etc.

Air is compressible, and its volume varies inversely as the pressure applied at uniform temperature. It also increases or expands, upon heating, a proportional amount depending upon the temperature to which it is heated.

The weight of dry air at atmospheric pressure (14.7 lbs. per sq. in.) is 0.0807 lb. per cubic foot.

One cubic foot of air raised 1° F. requires 0.02056 heat unit (B. T. U.).

One cubic foot of air raised from 0° to 70° F. requires 1.4392 heat units (B. T. U.).

Steam. Under ordinary atmospheric pressure of 14.7 pounds per square inch, water boils at 212° F., passing off as steam, the temperature at which it boils varying with a variation in the pressure. Steam is perfectly transparent, colorless, dry, and wholly invisible except when partially condensed, when the spray or mist makes it visible.

Dry steam is steam not containing any moisture. It may be either saturated or superheated.

Wet steam is steam containing free moisture in the form of spray or mist, and has the same temperature as dry saturated steam of the same pressure.

Saturated steam is steam in its normal state—that is, steam whose temperature is that due to its pressure, by which is meant steam at the same temperature as that of the water from which it was generated and upon which it rests.

Superheated steam is steam at a temperature above that due to its pressure after leaving the liquid from which it is generated.

A British thermal unit (B. T. U.) is the quantity of heat required to raise one pound of water one degree Fahrenheit.

The **total heat of water** is the number of British thermal units needed to raise one pound of water from 32° F. to the boiling point, under the given pressure.

The **latent heat of steam** is the number of British

thermal units (965.7) required to convert one pound of water, at the boiling point, into steam of the same temperature. This is also the **unit of evaporation.**

The **total heat of saturated steam** is the number of heat units required to raise a pound of water from 32° F. to the boiling point, at the given pressure, plus the number required to evaporate the water at that temperature.

The **specific heat of steam** is the quantity of heat required to raise the temperature of one pound of steam through one degree of temperature. In British units and near the saturation temperature, it equals, at constant pressure, 0.48.

The **specific gravity of steam** at any temperature and pressure, as compared with air of same temperature and pressure, is approximately 0.622. One cubic inch of water evaporated into steam at 212° F. becomes 1,646 cubic inches—that is, nearly one cubic foot.

Water in contact with saturated steam has the same temperature as the steam itself. Water introduced into superheated steam will be vaporized until the steam becomes saturated, and its temperature becomes that due to its pressure. Cold water, or water at a lower temperature than that of the steam, introduced into saturated steam, will condense some of it, thus lowering both the temperature and pressure of the rest until the temperature again equals that due to its pressure.

Heat. Unit of heat is a standard or term (B.T.U., British Thermal Unit) for measuring the amount of heat absorbed or emitted during any operation by any body or substance. It is the quantity of heat required to raise one pound of water 1° in temperature, Fahr., at sea-level.

Specific heat is the capacity of a substance for heat. It is the number of heat units necessary to raise the temperature of the body 1° F.

Latent heat is the heat absorbed during evaporation, or it is the heat necessary to change water at 212° into steam at that temperature.

Transmission of heat: First, by **radiation,** that is, the heated body giving out its heat in rays; second, by **convection,** the heat being conveyed from the heated body by currents or flues, etc.; third, by **conduction,** the heat passing from the heated body to the colder one when in contact.

A **unit of temperature** is 1° F., or $^{1}/_{180}$ part of distance between freezing point, 32°, and boiling point, 212°, on Fahrenheit scale.

A **thermometer** is an instrument for indicating the **intensity** (not quantity) of heat. The thermometer scale upon which the intensity of heat is indicated is an arbitrarily chosen scale. The two scales in most general use are the **Fahrenheit** and the **Centigrade.**

The Fahrenheit scale is used most generally in domestic, commercial, and industrial fields. Its lowest point, zero (0°), designates the lowest point to which mercury will fall in a tube when surrounded by a mixture of salt and ice. The point at which water freezes—called the **freezing point** (32°)—is noted, and the point at which water boils under normal conditions is noted at 212°; the distance between is divided into 180 equal divisions called **degrees.**

The Centigrade scale is divided into 100 equal divisions called **degrees** between the freezing point of water (0°) and its boiling point (100°) under normal conditions. These points and divisions are calibrated or marked upon a glass tube containing mercury, the expansion of which by heat indicates the number of degrees, or the temperature.

The distance from 32° (freezing point) to 212° (boiling point), or 180° Fahrenheit, is equal to the distance 0° (freezing point) to 100° (boiling point) on the Centigrade scale; or each degree on Fahrenheit thermometer is $^{100}/_{180}$ or $^{5}/_{9}$ of a degree on the Centigrade. Therefore, to convert Fahrenheit temperatures to Centigrade temperatures, it is necessary to subtract 32 (degrees) and multiply by $^{5}/_{9}$. To convert Centigrade temperatures to Fahren-

heit temperatures, multiply by $^{9}/_{5}$, and then add 32 (degrees).

Temp. C.=(Temp. F.—32°)$^{5}/_{9}$.

Temp. F.=(Temp. C.×$^{9}/_{5}$)+32°.

TABLE XXXI

Heat and Power Equivalents

Unit	Equivalent Value in Other Units
1 H. P. per hour=	.746 K. W. hour. 1,980,000 ft.-lbs. 2,545 heat units. 273,740 K. G. M. .175 lb. carbon oxidized with perfect efficiency. 2.64 lbs. water evaporated from and at 212° F. 17.0 lbs. water raised from 62° F. to 212° F.
1 H. P.=	746 Watts. .746 K. W. 33,000 ft.-lbs. per minute. 550 ft.-lbs. per second. 2,545 heat units per hour. 42.4 heat units per minute. .707 heat unit per second. .175 lb. carbon oxidized per hour. 2.64 lbs. water evaporated per hour from and at 212° F.
1 Heat Unit 1 (B. T. U.)=	1.055 Watt seconds. 788 ft.-lbs. 107.6 kilogram meters. .000293 K. W. hour. .000393 H. P. hour. .0000688 lb. carbon oxidized. .001036 lb. water evaporated from and at 212° F. A unit of heat (British thermal unit) is the quantity of heat required to raise 1 pound of water 1° Fahr. in temperature, at sea level.
1 Heat Unit per sq. ft per minute=	.122 Watt per sq. inch. .0176 K. W. per sq. foot. .0236 H. P. per sq. foot.
1 lb. carbon oxidized with perfect efficiency=	14,544 heat units. 1.11 lbs. anthracite coal oxidized. 2.5 lbs. dry wood oxidized. 21 cubic feet illuminating gas oxidized. 4.26 K. W. hours. 5.71 H. P. hours. 11,315,000 ft.-lbs. 15 lbs. water evaporated from and at 212° F.
1 lb. water evaporated from and at 212° F.=	.283 K. W. hour. .379 H. P. hour. 965.2 heat units. 103,000 K. G. M. 1,019,000 Joules. 751,300 ft.-lbs. .0664 lb. of carbon oxidized perfectly.

English and Metric Measures

The data given on the following page will be found very helpful in reducing quantities from English to Metric measure, and vice versa. The tables cover linear, square, and cubic measure, measure of volume and capacity, heat quantities, and weights.

ENGLISH AND METRIC SYSTEMS

English Measures of Length

12 inches = 1 foot.
3 feet = 1 yard.
5½ yards = 1 rod.
40 rods = 1 furlong.
8 furlongs = 1 sta. mile.
3 miles = 1 league.

English Square Measure

144 sq. inches = 1 sq. foot.
9 sq. feet = 1 sq. yard.
30¼ sq. yards = 1 sq. rod.
40 sq. rods = 1 rood.
4 roods = 1 acre.
640 acres = 1 sq. mile.

English Cubic Measure

1,728 cub. in. = 1 cub. foot.
27 cub. ft. = 1 cub. yard.
2,150.42 cub. in. = 1 standard bushel.
1 cubic foot = about ⅘ of a bushel.
128 cu. ft. = 1 cord (wood).
40 cub. ft. = 1 ton (shpg.).
268.8 cub. in. = 1 standard gallon

English Measure of Heat Quantities

1 kilogram caloric = 3.968 British thermal units (B. T. U.).
1 pound caloric = 1.8 British thermal units (B. T. U.).
1 British thermal unit (B. T. U.) = 0.555 pound caloric.
1 British thermal unit (B. T. U.) = 0.252 kilogram caloric.

METRIC SYSTEM

Prefixes of Multiples and Sub-Multiples of Meter, Liter, and Gram

Deka = 10
Hecto = 100
Kilo = 1,000
Deci = 0.1
Centi = 0.01
Milli = 0.001

10 millimeters = 1 centimeter.
10 centimeters = 1 decimeter.
10 decimeters = 1 meter.
10 meters = 1 dekameter.
10 dekameters = 1 hectometer
10 hectometers = 1 kilometer.

METRIC EQUIVALENTS

Linear Measure

1 centimeter = 0.3937 in.
1 decimeter = 3.937 in. = 0.328 ft.
1 meter = 39.37 in. = 1.0936 yards.
1 dekameter = 1.9884 rods.
1 kilometer = 0.62137 mile.
1 in. = 2.54 centimeters or 0.254 meter
1 ft. = 3.048 decimeters or 0.3048 meter
1 yard = 0.9144 meter.
1 rod = 0.5029 dekameter.
1 mile = 1.6093 kilometers.

Surface or Square Measure

1 sq. centimeter = 0.1550 sq. in.
1 sq. decimeter = 0.1076 sq. ft.
1 sq. meter = 1.196 sq. yds.
1 are = 3.954 sq. rods.
1 hektar = 2.47 acres.
1 sq. kilometer = 0.386 sq. mile.
1 sq. inch = 6.452 sq. centimeters.
1 sq. foot = 9.2903 sq. decimeters.
1 sq. yard = 0.8361 sq. meter.
1 sq. rod = 0.2529 are.
1 sq. acre = 0.4047 hektar.
1 sq. mile = 2.59 sq. kiiometers.

Measure of Volume and Capacity

1 cu. centimeter = 0.061 cu. in.
1 cu. decimeter = 0.0353 cu. ft.
1 cu. meter } = { 1.308 cu. yards.
1 ster } = { 0.2759 cord.
1 liter = { 0.908 quart dry.
1.0567 quarts liq.
1 dekaliter = { 2.6417 gallons.
.135 peck.
1 hektoliter = 2.8375 bushels.
1 cu. inch = 16.39 cu. centimeters.
1 cu. foot = 28.317 cu. decimeters.
1 cu. yard = 0.7646 cu. meter.
1 cord = 3.624 sters.
1 quart dry = 1.101 liters.
1 quart liq. = 0.9463 liter.
1 gallon = 0.3785 dekaliter.
1 peck = 0.881 dekaliter.
1 bushel = 0.3524 hektoliter.

Weights

1 gram = 0.03527 ounce.
1 kilogram = 2.2046 lbs.
1 metric ton = 1.1023 English tons of 2,000 lbs.
1 ounce = 28.35 grams.
1 lb. = 0.4536 kilogram.
1 English ton = 0.9072 metric ton.

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